Exploring Students' Progression in an Inquiry Science Curriculum Enabled by Mobile Learning

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Abstract—The research literature reports on designs of ubiquitous and seamless learning environments enabled by the integration of mobile technology into learning. However, the lack of good pedagogical designs that provide for sustainability and the inadequate investigation of learning outcomes remain major gaps in the current studies on mobile learning. This paper seeks to contribute to addressing these issues by reporting on a study concerning the principles of integrating mobile learning into a standards-based science curriculum. It also explores how mobile learning activities have impacted students' academic and activity performances in and out of the classroom over a whole academic year. Mixed methods were used to examine students' performances, and a yearly comparison was made for assessing students' progression in their conceptual understanding in science. Data analysis on students' test results, mobile learning artifacts, and their activity performances in the classroom suggested that they had improved in their conceptual understanding and self-reflection on these conceptual changes. Students were engaged in mobile learning activities both in the classroom and out of the classroom through sustained exposure to and experience of the mobilized science curriculum.

Index Terms—Mobile learning, pedagogical design, science curriculum, conceptual understanding

1 Introduction

For a long time, science, technology, engineering and mathematics (STEM) education has received considerable attention due to its importance in educating students for the global economy [1]. The Singapore ministry of education (MOE) considers STEM education as one of the main foci in primary education [2]. The call for information and communication technology (ICT) integration in education, as supported by the consecutive launches of three masterplans for ICT in education, is one of the contributing efforts for promoting STEM education in Singapore [3]. The latest master plan for ICT in education emphasizes the extension of integrating ICT into the curriculum that seeks to develop 21st century competencies (e.g., self-directed learning skills, and collaborative learning skills). Such pursuit requires more ICT-enabled innovations designed with the intention to cultivate students' competencies while they learn the academic content. The appropriation of mobile technology into school education is one of the many goals of the innovation efforts.

The research of market trends on smartphones suggests that in the year of 2013 the volume growth of smartphones reached 15 percent in Singapore [4]. With advances in smartphone technology, the use of these devices has become pervasive and ubiquitous in many societies. Recognizing the multiple functions of the smartphones and their educational value, educators have long advocated the adoption of mobile learning in schools [5], [6]. Research on technological design, pedagogical design, and implementation and evaluation of smartphone-enabled learning (or mobile learning in a broad sense) has been accumulating, yet challenges remain in supporting teacher enactment and documenting evidence of student learning in mobile learning [7]. Engaging students in a series of designed mobile learning activities has also become a challenging issue [8]. All these call for the design and development of effective mobile learning innovations to improve current teaching and learning. A review of current studies on mobile learning reveals the dearth of reported longitudinal studies. Few studies have explored the impact of sustainable mobile learning programs that are pegged at the curriculum level on student learning performance. The existing evidence is too scarce to inform future research and practice concerning school-based teaching and learning. Thus, it is important to conduct multi-year, longer-term studies that develop pedagogical design principles on how to integrate mobile learning into a standards-based science curriculum, and that trace students' progression in performance throughout the learning process. Progression mainly refers to students' improvement in conceptual understanding which is probed through examining their test and activity performance. This paper presents such a study that focuses on exploring changes in student performance brought about by a mobile technology supported science curriculum during a six-year project, "Bridging Formal and Informal Learning Spaces for Self-directed & Collaborative Inquiry Learning in Science". The study explicitly presents a long-term effort on investigating pedagogical designs for mobile learning as well as on exploring changes in students through their participation in mobilized science learning. In this paper, the relevant literature will be discussed, and the principles of integrating mobile learning into the standards-based science curriculum will be introduced and interpreted. Then the findings of students' performance improvement impacted by the innovative curriculum will be reported and

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discussed. Implications will be drawn to inform the design and implementation of mobile learning.

2 Literature Review

2.1 ICT Education in Singapore

Three masterplans for ICT in Education were consecutively released by MOE in 1997, 2002 and 2008 to drive the ICT integration into teaching and learning in every school in Singapore [9]. These stage-by-stage plans enable Singapore schools to establish basic infrastructure for the use of multimedia resources, improve teacher readiness for ICT use, and develop school-based ICT-supported curricula. The 2008 masterplan particularly expanded and deepened ICT integration into the curriculum by pushing ICT use beyond the classroom to transform learning so as to develop 21st century competencies in students [10].

As one of the pioneering ICT-supported science learning projects in Singapore that respond to the 2008 masterplan, our project which employs a design-based research approach has been ongoing and sustained for about six years in a primary school. At this point of writing, with the availability of good mobile applications, excellent network infrastructure, and adequate school readiness, the mobile learning innovation is being scaled-up to five other Singapore schools. It attempts to empower better alignment between ICT education in Singapore and the international ICT education reform, and to prepare learners for the 21st century.

2.2 Pedagogical Design of Mobile Learning

Combining appropriate pedagogical strategies for enhanced learning applications has been a critical issue in mobile learning research that goes beyond the integration of suitable mobile technologies [11]. It has been extensively discussed that, like any other learning activity, the design of mobile learning activities should be driven by specific learning objectives [12]. Pedagogy has been identified as a critical issue in mobile learning and the mutual interaction between teaching and learning can potentially change the nature of their relationships [13].

Researchers have placed increasing emphasis on establishing pedagogical principles based on the attributes of the mobile learning environment configured for teaching and learning. For instance, a pilot study on mobile experiential learning created a new way of inquiry-based mobile learning in science: in-class questioning, out-of class field trip observation, on site reflection, hands-on experimentation, and learning artifacts creation, sharing and evaluation [14]. Relevant studies on ThinknLearn, mobile plant learning system, mobile tour system, and nQuire indicate positive impact on both teachers and students. They all highlighted the integration of appropriate pedagogical principles supported by technology design [15], [16], [17], [18]. These studies affirm the potential of mobile learning in enriching science education. More importantly, evidence has been obtained for supporting the claim that combining mobile learning systems/apps with appropriate pedagogical approaches (e.g., inquiry-based principles, knowledge building, and collaborative learning) can create special educational value for students' science learning.

2.3 Issues of Mobile Learning Research

So far, most conversations on mobile learning have been focused on systems/apps design and their evaluation without interpreting how such systems/apps were integrated into the learning activities, how students responded to these activities, and what students accomplished in their learning. Studies mostly discuss the use of mobile phones for delivering course materials, learners' preparedness for and usage of the mobilized form of learning, and learners' satisfaction level and learning experiences. Yet none of these studies are directly related to the use of mobile phones for subject-related purposes [10]. Sustainable mobile learning programs that are designed for teaching and learning a standards-based curriculum are rare.

To further improve the educational use of mobile technologies, efforts should be made to integrate the school curriculum into the research design, and thus to improve the balance between research needs and school needs. However, recent research on mobile learning focuses more on studying learning in the informal context. Few mobile activities investigate the connection of learning between the formal and informal contexts. Thus, evidence about synergetic effects of linking these two contexts or environments of mobile learning is inadequate [19]. As mentioned before, most studies focus on examining short-lived learning experiences and reporting findings based on students' self-reports (i.e., interviews, questionnaires and surveys). Few efforts have sought to investigate the learning trajectory of students' using mobile technologies for learning over sustained periods of time. To address these issues, we have designed and developed an innovative standards-based science curriculum supported by mobile learning, and explored how this innovation had influenced students' science learning in and out of classroom. This study proposes a mobile learning design that bridges formal and informal learning contexts, and presents new findings of students' performance in the mobilized science curriculum.

3 Research Questions and Purposes

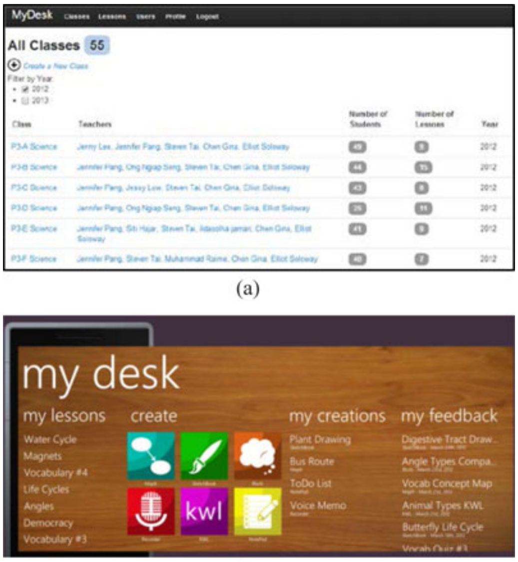
This study was conducted to answer the following research questions:

1. How can we integrate mobile learning into a standards-based science curriculum?
2. What are students' learning progressions in and out of classroom impacted by the mobile technology-supported curriculum?

4 Context

4.1 M5ESC and MyDesk Learning System

Our project has iteratively and progressively developed the innovative science curriculum "Mobilized 5E Science Curriculum" (M5ESC) via design-based research in Singapore since 2008 [20]. It is a first attempt to systematically and comprehensively explore the integration of mobile learning with a science curriculum via a long-term and stage-by-stage intervention. The curriculum is mapped to national science curriculum standards, and covers all standard materials required in a primary school. Aligning with the primary science syllabus [9] and Singapore MOE's advocacy



(a)

(b)

Fig. 1. (a) Teacher module of MyDesk. (b) Student module of MyDesk.

on the development of 21st century competencies in science education, M5ESC aims to promote students' conceptual understanding and critical learning skills (e.g., collaborative learning skills, self-directed learning skills, and reflective thinking skills) [21], [22].

The lesson design of M5ESC is based on 5E (Engagement-Exploration-Explanation-Elaboration-Evaluation) instructional model that embodies constructivist learning theories. 5E consists of the following phases: engagement (accessing students' prior knowledge and engaging students in the exploration of science phenomena), exploration (providing opportunities for students to investigate the science phenomena or principles), explanation (encouraging students to interpret their understanding of science phenomena and relevant principles or concepts), elaboration (challenging and deepening students' understanding of the phenomena through new experiences), and evaluation (assessing students' understanding via appropriate assessment methods) [23]. Each phase has a specific function and contributes to the teachers' coherent instruction and to the learners' understanding of scientific and technological knowledge, and the enhancement of attitudes, and skills.

M5ESC lessons flexibly incorporate mobile apps from a learning system called MyDesk, a multifunctional tool installed in Windows-based smartphones. The MyDesk application suite is developed by Elliot Soloway and his undergraduate students at the University of Michigan [24]. The system consists of the teacher module (Fig. 1a) and the student module (Fig. 1b) [25].

The teacher module provides an authoring tool for teachers to "create" mobile activities using different learning tools according to M5ESC pedagogical principles. It also supports teachers to review, evaluate and retrieve students' learning artifacts after lessons.

In the student module, students can access the activit- ies designed by their teacher, construct learning artifacts, and compose self-reflections using the assigned learning tools. Specifically, MyDesk combines learning tools with different functions. The design is intended to facilitate students to develop sophisticated and systematic understanding of scientific concepts, enhance skills in modelling, reasoning and reflective thinking, and foster self-directed learning skills in and out of the classroom [26], [27]. Hence, the learning tools in MyDesk include:

kwl *(KWL)*. KWL is the acronym from "what do I already **K**now? what do I **W**ant to know? what have I **L**earned?" It is a self-reflection tool supporting students' reflection upon learning process and conceptual changes through responding to the three questions above to allow students to learn in a self-regulated way.

(Sketchbook). An animation/drawing and picture annotating tool to assist students in establishing connections between knowledge learned in the classroom and knowledge applied outside the classroom.

(MapIT). A concept mapping tool that allows students to develop conceptual understanding through creating, sharing, and exploring concept maps.

(NotePad). A data recording tool for students to record the results or process of experiments, field trips, and observation of teacher demonstrations.

(Blurb). A question setup tool which facilitates the teacher to set up specific questions to probe students' opinions or feedback on their inquiry activities or their understanding of knowledge.

(Recorder): A voice recorder tool for students to record the process of the experiment, field trips and the observation of teacher demonstrations. Students' reflections and conclusions are also recorded for the teacher to review their progress and improvement in inquiry.

Other supporting tools (e.g., mobile blog, online discussion forum, video/photo camera, and a search engine) are also incorporated for use by students. Students use these tools to create their learning artifacts, and then upload them to the MyDesk server. Upon viewing these artifacts, the teacher can provide feedback and grading of their learning artifacts.

In the M5ESC classroom, the constructivist learning theory supports inquiry by placing the focus on student ideas, questions, and understanding, rather than on teacher delivery of content [28].Teachers are encouraged to apply constructivist teaching approaches to ask questions, conduct mobile activities, interact with students, and scaffold students' learning. Equipped with mobile devices, students go beyond classroom activities that merely require mimicking what the teacher says and does in the classroom. Instead they learn in personally meaningful ways by the use of learning tools [19].Various patterns of learning activities (e.g., individual inquiry, collaborative inquiry, and peer discussion) are mainly designed with the aim of developing students' sophisticated understanding of science and fostering their self-directed learning and collaborative learning skills. More-over, the pervasive use of mobile devices in and out of the classroom (e.g., botanic garden, home, science museum, and zoo) reflects the notion of seamless learning that features "learning anytime, anywhere" [29]. Students are encouraged to connect their classroom learning of science with their daily life experiences of science in authentic contexts. Fig. 2 represents the typical work flow of M5ESC.

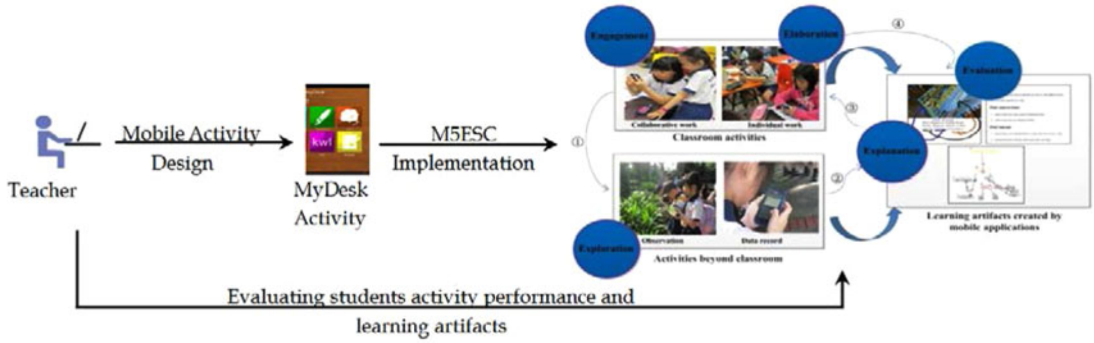


Fig. 2. The work flow of M5ESC.

4.2 Design Principles of Mobile Learning in M5ESC

The designed mobile learning activities in M5ESC aim at fully leveraging technological affordances both in and out of the classroom, addressing different cognitive levels of usage, and providing the opportunity for teachers to create ubiquitous learning environment that brings together real-world resources and digital world information. In thinking about how to integrate mobile technology into the standards-based curriculum, we propose a match of mobile tools with the M5ESC activities at the different cognitive levels (Table 1). The match is motivated by Starkey's 'Digital Age Learning Matrix' [30]. The main purpose of incorporating mobile activities into the curriculum is to facilitate knowledge construction, as well as to develop science inquiry skills. Level 1 activities include the use of NotePad or/and Recorder for collecting data and writing notes in field trips. KWL allows self-reflection on the connections between knowledge; hence it can be integrated into high cognitive levels of activities (i.e., Levels 2, 3 and 4). Sketchbook is an animation tool that is used for promoting students' ability to connect knowledge with daily experiences and for developing higher levels of conceptual understanding (i.e., Levels 5 and 6) through peer assessment of artifacts. Similar to Sketchbook, MapIT provides opportunities for students to share and discuss their conceptual understanding through drawing concept maps, and therefore the activities designed based on this tool are at the higher cognitive levels such as Levels 4, 5 and 6. Blurb is generally used for improving students' thinking and reasoning about the concepts through posing questions, which is appropriate for designing Level 2 and 3 activities.

Using these apps, students will have more opportunities to participate in different levels of mobile learning activities and they will construct higher levels of knowledge understanding through doing these mobile learning activities in M5ESC. Moreover, students will develop relevant learning skills. Table 2 presents the lesson design of "Exploring Materials" at the Primary 3 (P3) level. We list activities (either in and out of the classroom, or both) and their cognitive levels with a focus on how the technology is integrated into the different phases of the 5E instructional model. This is the typical lesson plan of M5ESC. Five lessons are designed by applying the principles of the 5E inquiry model.

Various classroom activities and home activities are designed to help students investigate and familiarize themselves with the properties of materials. Compared with the traditional class, students can receive substantial opportunities to explore scientific phenomena and understand the scientific concepts by themselves or co-construct understanding with their peers. Furthermore, they can use the mobile learning tools for facilitating their doing and thinking in inquiry in various contexts. Overall, the principles of seamless learning can be described as encompassing formal and informal learning contexts (e.g., classroom and home), encompassing personalized and social learning (e.g., individual work and collaborative work), existing across time (e.g., in class time and out of class time) and locations (e.g., in the classroom and outside the classroom), and providing ubiquitous knowledge access (e.g., ubiquitous internet information) [29].

The design of M5ESC is aligned with the vision that learning needs to be learner-centred, situated, collabora tive, ubiquitous, and continuous. The use of technology has become more personalized, user-centred, mobile, networked, ubiquitous, and durable in M5ESC [31]. The incorporation of different tools facilitates the blend of different learning activities residing onto one learning environment

TABLE 1
Proposed Cognitive Levels of Learning Activities in M5ESC

Mobile tools	Level 1: Doing	Level 2: Thinking about connections	Level 3: Thinking about concepts	Level 4: Critiquing and evaluating	Level 5: Creating knowledge	Level 6: Sharing knowledge
KWL		√	√	√		
Sketchbook				√	√	√
MapIT				√	√	√
Blurb		√	√			
NotePad	√					
Recorder	√					

TABLE 2
Design of Activities for the Topic on "Exploring Materials"

Lesson sequence	Activities	Technology Integration	Cognitive Levels
Lesson 1: Engagement	Classroom activity: Teacher demonstrates the properties of materials (e.g., hardness)	Camera, search engine	Level 1 + Level 2
	Home activity: students draw concept maps of material classification	MapIT evaluation	Level 4
Lesson 2: Exploration	Classroom activity: Teacher reviews and identifies inappropriate conceptions of materials classification in KWL; students collaboratively design and conduct experiments to explore the properties of materials.	KWL evaluation, Camera, Notepad	Level 4 + Level 1
	Home activity: • Students take pictures of materials in their daily life and describe their properties and usefulness; • Students write their thoughts and reflection in KWL.	Camera, video camera, KWL reflection, Sketchbook	Level 1 + Level 2 + Level 3
Lesson 3: Explanation	Classroom activity: Teacher identifies inappropriate conceptions in KWL and Sketchbook; and guides students to improve their understanding.	KWL evaluation, Sketchbook evaluation,	Level 4 + Level 5
	Home activity: Students design and conduct experiments independently to demonstrate properties of materials in their daily life.	camera, video recorder, Notepad, KWL reflection	Level 1 + Level 3
Lesson 4: Elaboration	Classroom activity: Students present their work done at home; students peer-critique and share their ideas; teacher explores and stimulates students' conceptual understanding by further explanation and summary.	KWL evaluation, Sketchbook evaluation	Level 4 + Level 5 + Level 6
Lesson 5: Evaluation	Classroom activity: Students apply their understanding to answer test questions.	-	-

[32]. M5ESC allocates a substantial amount of time for doing the mobile learning activities. Teachers and students interact more frequently in the discussion and sharing of work generated by mobile tools. Formative assessment is regarded as an integral part of instruction and an important source for students and teachers to make reflections on learning and teaching [33]. Students' performance in mobile learning activities is identified as an important indicator for assessing their learning gains in M5ESC as their performance signifies involvement in learning. In this paper, our focus will be on students' performance both in and out of the classroom with the intention of identifying students' progression in the mobile learning activities throughout the long-term intervention.

5 Methods

5.1 Participants

In the year of 2012, M5ESC was scaled at the whole P3/Grade 3 level in a primary school in Singapore. In this study, the 2012 P3 ($n = 299$), 2013 P3 ($n = 315$), and 2013 P4 ($n = 299$) cohorts (aged 10-11) were selected as the participants. Each cohort was comprised of eight classes. The 2012 P3 cohort progressed into P4 in 2013 and constituted the 2013 P4 cohort. This enabled us to conduct yearly comparison of students' performance, and to examine students' yearly progression in and out of the classroom. As mobile learning activities were expected as a routine in this school, each student was assigned a smartphone as the mobile learning device and allowed to bring the learning device into and out of the classroom. There were five teachers teaching the P3 and P4 cohorts respectively, each in charge of one or two classes. During the academic years of 2012 and 2013, teachers and researchers worked together on a weekly basis to co-design and elaborate the lessons. Professional Development (PD) on pedagogical principles of M5ESC for teachers was administered. Researchers provided feedback about teacher design and enactment of M5ESC lessons. The participating teachers were enthusiastic about the curriculum innovation and would like to transform their pedagogical approaches to science instruction from the traditional pedagogical approaches to the constructivist pedagogical approaches through long term enactment of the innovative curriculum. All teachers performed actively in PD and lesson co-design in the weekly teacher-researcher meetings. They had strong willingness to receive feedback on curriculum enactment and to elaborate their teaching strategies. The students and their parents also appreciated the educational value of the smartphones. The parents supported their children to use the smartphone out of the classroom for extending and elaborating their learning.

5.2 Data Sources and Analysis

Data was collected on teacher performance in curriculum enactment, student performance in and out of the classroom, and teacher and student responses to MyDesk activities. Classroom observation was conducted in each class throughout the whole school years of 2012 and 2013. Field notes were used for recording the lesson sequence and key instructional events in the class (i.e., questions, interaction, experiments, and mobile activities). A classroom observation sheet was designed for collecting data on teacher and student performance on the key instructional events. Researchers retrieved and reviewed students' work and teacher feedback in MyDesk to explore student learning performance (i.e., engagement, concept understanding, and reflective thinking) out of the classroom. In Singapore primary schools, all students participate in Semestral Assessment 1 (SA1) which is administered at the end of the first semester, and Semestral Assessment 2 (SA2) administered at the end of the second semester. These two examinations were considered as summative assessments of students' achievements in science learning, and the results were used by the school as key indicators for evaluating students' progress throughout the year. The total score of SA1 and SA2 was 100 for each, with 60 marks for multi-choice questions (MCQ) (two marks for each item) and 40 marks for open-ended questions (OEQ) (2 marks for each item). As the official and standard tests conducted at the whole level in the pilot school each year, SA1 and SA2 had been reviewed and validated by a group of experienced teachers in the school. The difficulty levels of SA1 and SA2 were comparable at the item level. To test the reliability of the tests, a mock-up test with items of similar difficulty level and structure was conducted before each standard test. The mock-up test results were analyzed to help revise the inappropriate items.

This study used three data sources for analyzing the progression of students' learning performance from school year 2012 to year 2013. The 2012 and 2013 data sets were selected in that M5ESC was being scaled up during these two years and student data for the whole level could be retrieved and compared. The student data includes:

1. MyDesk learning artifacts: work completion rate and levels of work quality.

   A cross-year comparative study of 2012 P3 and 2013 P4 students' responses to MyDesk activities were conducted to uncover students' progression in constructing MyDesk learning artifacts. The completion rate of each task was analyzed to investigate students' engagement in mobile learning activities that occurred out of the classroom (i.e., Recorder, Blurb, KWL, MapIT, Sketchbook, and Notepad activities). If students were interested and engaged in the MyDesk learning activities, the completion rate was expected to be high and vice versa. The quality level of work produced in KWL, Sketchbook, and MapIT activities, the activities that had higher completion rate and used more frequently, was identified as the major indicator of students' progression in conceptual understanding and relevant thinking skills (i.e., reflective thinking skills in KWL, systems thinking skills in MapIT and cognitive levels of knowledge in Sketchbook and MapIT) [34].
2. SA1 and SA2 results: students' achievements in standardized tests.

   SA1 and SA2 scores of 2012 and 2013 P3 cohorts were compared to provide more evidence for supporting our research hypothesis that students would benefit more in reasoning and conceptual understanding with the use of M5ESC.[1]
3. Students' activity performance in the classroom.

   A qualitative discussion of students' performance in sharing, discussion and experimentation was conducted for assessing students' attitudes towards the classroom activities and their involvement in these activities.

The data analysis was conducted by two researchers, and the inter-rater agreement of MyDesk coding reached 93 percent.

6 Findings

6.1 Progression in Performance

One-sample t-test (Table 3) was conducted to compare 2012 and 2013 P3 SA1 and SA2 results.[2] The result showed that the whole P3 cohort made a significant increase of 7.69 percent in total score from SA1 to SA2 ($t = 6.584$, $p < .05$) in 2012. It is worthwhile to note that such progress was mainly attributed to their increase in OEQ scores (27.04 percent) ($t = 11.845$, $p < .05$). They experienced a slight (not significant) increase in MCQ scores (0.49 percent). Specifically, the Low Ability (LA) group, out of the three ability groups, achieved the highest MCQ gains (13.16 percent) ($t = 2.487$, $p < .05$), OEQ gains (60.30 percent) ($t = 7.071$, $p < .05$) and total gains (23.49 percent) ($t = 4.809$, $p < .05$). This suggested that the LA group benefited the most in terms of conceptual understanding and in-depth thinking about the concepts after more participation in M5ESC. Although HA group only had a slight decrease in MCQ (−5.04 percent) ($t = -5.987$, $p < .05$), they achieved significant OEQ gains (11.71 percent) ($t = 7.798$, $p < .05$).The MA group achieved significant OEQ gains (29.55 percent) ($t = 8.835$, $p < .05$) as well. These reflected that all students gained more sophisticated understanding of the concepts, as well as reasoning skills in responding to the why-type questions in OEQ.

As for the second scaling-up year, P3 students performed as well as the previous P3 students did in 2012. In 2013, the improvement in total score was significant ($t = 13.626$, $p < .05$) and the total gains were more than 2012 total gains (10.07 percent). All the three ability groups achieved significant gains in total scores. Similar to the results of 2012, they achieved more gains in responding to OEQ, especially for the LA group (23.55 percent) ($t = 4.587$, $p < .05$).The MA

1. Comparison of the 2012 and 2013 SA1 and SA2 results was conducted at the P3 level, as the one-year intervention could indicate students' conceptual understanding impacted by M5ESC.

2. The eight classes were grouped into three ability levels, namely, HA (High Achievement), MA (Mixed Achievement) and LA (Low Achievement) based on their prior performances at the P1/P2 level.

TABLE 3
SA1/SA2 Ha-Ma-La Gains of P3 in Years 2012 and 2013

School year		*MCQ gains*	*OEQ gains*	*Total Gains*
2012	All	0.49%, t = .406	27.04%*, t = 11.845	7.69%*, t = 6.584
	HA	−5.04%, t = −5.987	11.71%*, t = 7.798	5.04%, t = .535
	MA	0.91%, t = .595	29.55%*, t = 8.835	8.62%*, t = 6.047
	LA	13.16%*, t = 2.487	60.30%*, t = 7.071	23.49%*, t = 4.809
2013	All	6.91% *, t = 5.978	20.33%*, t = 18.514	10.07%*, t = 13.626
	HA	3.53%*, t = 3.24	16.30%*, t = 15.021	7.7%*, t = 10.1
	MA	10.98% *, t = 5.52	23.07%*, t = 12.527	13.86%*, t = 10.643
	LA	6.41%, t = 1.449	23.55%*, t = 4.587	8.03%*, t = 3.198

**: Statistically significant; SA1-Semestral assessment 1, SA2-Semestral assessment; MCQ-Multiple choice questions, OEQ-Open ended questions.*

group had more improvement in MCQ scores (10.98 percent) ($t = 5.52$, $p < .05$), and received most gains in total scores (13.86 percent) ($t = 10.643$, $p < .05$). Compared to the performance of the 2012 P3 cohort, the 2013 P3 cohort achieved comparatively more balanced gains in the total scores (HA: 7.7 ; MA: 13.86%; LA: 8.03%).

In summary, both 2012 and 2013 P3 cohorts had achieved significant gains in total and OEQ scores. The improvement in OEQ scores was the major reason for the improvement of the total score. MA and LA groups attained more SA1/SA2 gains than the HA group did, especially in OEQ scores. The results showed that from the one-year experiencing of the M5ESC curriculum, students could attain significant improvements in their conceptual understanding of science, particularly in the reasoning and explanation of the "why" questions.

6.2 Progression in Mobile Learning Performance

6.2.1 Students' Engagement in MyDesk Learning Activities

In 2012 P3 M5ESC, MyDesk learning tools were integrated into five science topics: diversity of plants, fungi, materials, system: plants and their parts, and system: digestion. When students progressed into P4, MyDesk learning tools were incorporated into five topics, namely, cycles, matter, interactions, heat, and light.

Table 4 shows the average completion rate of these activities using the assigned learning tools in 2012 and 2013. As Table 4 shows, P3 mobile learning activities incorporated the use of Recorder, Blurb, KWL, MapIT, Sketchbook and Notepad. P4 mobile learning activities incorporated the use of KWL, MapIT and Sketchbook. The result suggested that students provided more responses to these mobile activities in 2013/P4 (with an average completion rate of 44.85 percent among 299 students) than they did in 2012/P3 (with an average completion rate of 24.09 percent among 299 students). This indicated that these students engaged more in the mobile learning activities at the P4 level.

TABLE 4
The Comparison of MyDesk Activity Completion Rates in 2012 and 2013

Year	Recorder	Blurb	KWL	MapIT	Sketchbook	Notepad	Average Rate
2012	7.25%	23.73%	48.63%	24.42%	24.84%	4.00%	24.09%
2013	-	-	53.44%	36.88%	50.56%	-	44.85%

Specifically, the P3 students in 2012 were involved in KWL learning activities than in other activities (KWL: 48.63%). Their participation in Sketchbook, MapIT and Blurb activities were quite similar (Sketchbook: 24.84%; Blurb: 23.73%; MapIT: 24.42%). When they were in P4 in 2013, they achieved a higher completion rate in KWL (53.44 percent), MapIT (36.88 percent) and Sketchbook activities (50.56 percent) than they did in the previous year. In particular, the participation rate of the KWL and Sketchbook activities increased. This revealed that students were more engaged in using KWL and Sketchbook to describe and reflect their understanding and to relate their understanding with their daily life experiences.

Paired samples t test indicated the significant difference in usage between learning tools in 2012, such as between Recorder and KWL ($t = -7.990$, $p = 0.000 < 0.05$), KWL and MapIT ($t = 5.183$, $p = 0.000 < 0.05$), as well as Sketchbook and KWL ($t = 5.132$, $p = 0.000 > 0.05$). In 2013, significant difference in usage was found between KWL and MapIT, and MapIT and Sketchbook. This suggested students' discrepant involvement in different mobile learning activities out of the classroom. Students, with different skills, knowledge, and guidance and feedback from their teacher, used different tools to extend their learning.

Through this comparison, we got more insights into students' involvement in MyDesk and their levels of engagement in each mobile activity. The overall results showed that students had engaged more in the mobile learning activities after they had participated in a series of tasks even without teachers' monitoring or facilitation out of the classroom. In particular, they used more reflective thinking skills via engaging in KWL activities. The comparison also provided valuable information for teachers to improve their design, elaboration, and evaluation of the mobile learning activities for students, which would prompt students' motivation in doing mobile activities.

6.2.2 Work Quality of MyDesk Learning Activities

In the study, students' learning artifacts constructed by mobile learning tools of KWL, MapIT and Sketchbook (which received higher completion rates) in the MyDesk learning system were selected and categorized into the different quality levels. We compared the distribution of different categories of learning artifacts created by the students in 2012 P3 and 2013 P4 to get insights into their learning progression in the conceptual understanding.

KWL reflection. KWL in MyDesk is organized in three sections:

- What I know—refers to student's prior knowledge of the topic/task before the lessons;

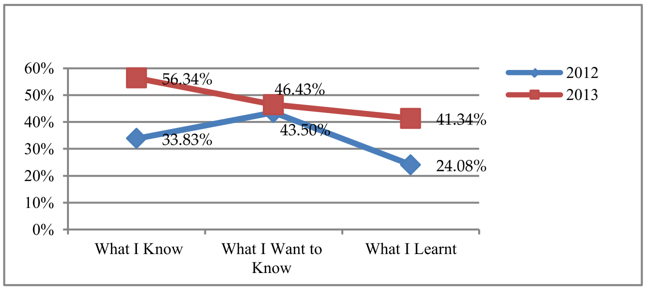


Fig. 3. Students reflection proportion in KWL.

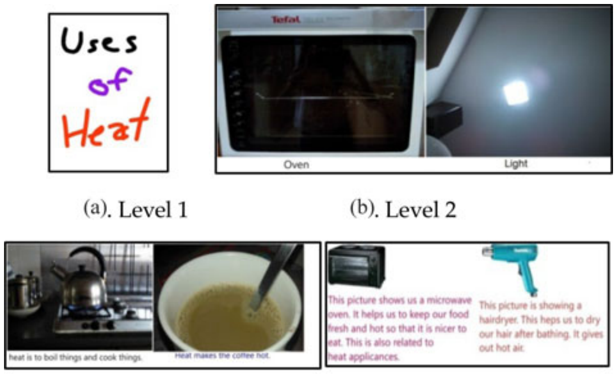
- What I want to know—refers to student's further thinking about the prior knowledge and the knowledge he/she wants to elaborate in the process of lessons;
- What I learnt—refers to student's self-reflection on the knowledge he/she has learned about the assigned topic.

Hence, KWL activity design aims to expose students' prior knowledge, detect their misconceptions and improve their self-reflective thinking skills. In our study, the last section: What I learnt was identified as the major indicator of evaluating students' levels of self-reflection, in which, they were expected to reflect about what they learnt and how their understanding needed to be improved after the lessons. This level of reflection has been identified as deep reflection [35].

Data analysis of students' work in KWL in 2012 and 2013 suggested that students not only participated more actively in responding to KWL activities, but also improved their levels of reflective thinking. Fig. 3 shows the completion rate for each section. Besides the overall increase of participation in KWL activities in 2013 (the average completion of all sections increased from 33.8 to 48.1 percent), student responses to each KWL section also increased. Compared to the 24.08 percent completion rate of "What I Learnt" in 2012, the completion rate of 2013 (which was 41.43 percent) was high. This means that students developed deeper thinking of their conceptual understanding and could conduct higher reflection upon what they learnt. Moreover, students became more willing to share their prior knowledge (in the section of "What I Know", the completion of which increased from 33.83 to 56.43 percent). Generally, in 2012, only 20 percent students completed all the three sections of KWL. In 2013, that percentage was doubled (40 percent). This suggested that more and more students could manage to examine their prior knowledge and identify the new knowledge gained that could help elaborate and extend their prior knowledge. In summary, they had gradually developed their reflective thinking skills as they got into P4. They also became more skillful in reflecting upon their understanding. Below are some typical responses extracted from the KWL completed in 2013.

P4 Students' reflections about Cycles in "What I learnt":

- *A pattern that repeats itself continuously is a cycle.*
- *A routine, timetable or schedule is not cycles because we can change it.*
- *If we take away something that creates a cycle or in a cycle it won't reproduce.*



(a). Level 1 (b). Level 2

(c). Level 3 (d). Level 4

Fig. 4. Students' responses to Sketchbook task.

- *The life cycles of different living things have different kinds of stages.*
- *Some cycles have three stages while some have four stages it doesn't mean that the four stages cycle will live or last longer.*

P4 Students' reflections about Magnets in "What I learnt":

- *There are always two poles at the end of the magnet. They are called North and South poles. No matter what shape it is, it will still have poles. Usually, metal paper clips can be attracted to magnet.*
- *Poles that are like will push each other away. We said that it repels away.*
- *If you drop a magnet many times, heat it over a flame and hammered it many times, it will lose magnetism.*
- *As the number of strokes increases, the number of clips also increases.*
- *Which means if I want to make a stronger temporary magnet, I have to stroke more times in the same direction and use the same pole.*

Sketchbook construction. In M5ESC, Sketchbook is used to design out-of-classroom mobile activities for students to connect their knowledge with the daily life experiences. In P4, home-based experiments that incorporated the use of Sketchbook were designed for students to observe and record the growth of plants, the lifecycle of mealworm, the use of heat, and the use of magnets in the surroundings. In P3, Sketchbook activities were designed to provide students extensive opportunities to explore the type, properties and value of materials, fungi, and the comparison between moist and dry bread. We coded Sketchbook activities into four quality levels based on the modified knowledge integration scoring rubric [36]:

- *Level 1(Non-relative pic/text)*. Students have irrelevant ideas and make incorrect links with the task.
- *Level 2 (Relative pic/text)*. Students have relevant ideas and make partial correct links with the task.
- *Level 3 (Relative pic/text with simple explanations)*. Students have relevant ideas and make correct links with the task and provide simple explanations.
- *Level 4 (Relative pic/text with simple explanations)*. Students have relevant ideas and make correct links with the task and provide elaborated explanations.

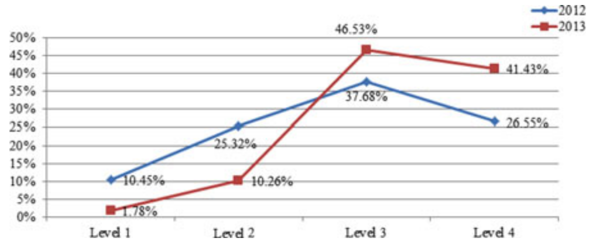


Fig. 5. Distribution of quality levels of Sketchbook.

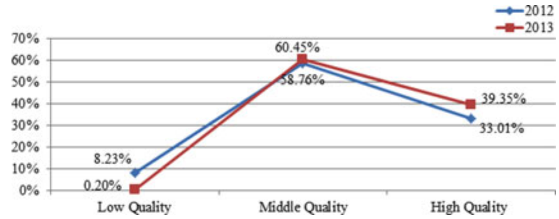


Fig. 7. Distribution of quality levels of concept maps.

Fig. 4 illustrates the typical responses students provided to a Sketchbook task: *Using your phone, take pictures to show the presence of heat and insert them into the Sketchbook. Elaborate on how heat is being used in your daily life and activities and where the heat comes from*. The students' Sketchbook learning artifacts were of different quality levels. These artifacts reflected students' different levels of understanding of the topic and their ability to connect classroom knowledge with daily life experiences.

From analysing the completed Sketchbook learning artifacts (2012: n = 75; 2013: n = 151), we found that most students responded positively in their work. Their efforts in constructing learning artifacts could be reflected by the pictures they captured in their daily life. We also noticed that some pictures were captured with the assistance from their parents. Fig. 5 shows the distribution of the Sketchbook learning artifacts at the different quality levels. Thus, compared to their 2012 performance, students in 2013 performed better in Sketchbook activities.

Besides the increase in completion rate, the proportion of L3 and L4 artifacts, the high level ones, had increased from 37.68 to 46.53 percent, and from 26.55 to 41.43 percent respectively. This suggested that more students could relate their daily life experiences with their conceptual understanding and describe the phenomena in a deeper way. Fig. 6 shows some selected high level Sketchbook artifacts constructed in the lessons of Magnet from the topic of Interactions (the task being: *use your mobile phones, take pictures to show how magnets are used in your daily life*). These three artifacts presented the products of magnets in the daily life captured by the students, and each one was annotated with the description of how the magnet was used in the product. These further showed that students developed better understanding of the concepts and had better application of knowledge.

Meanwhile, the dramatic decrease of L1 (from 10.45 to 1.78 percent) and L2 (from 25.32 to 10.26 percent) artifacts further suggested students developed better understanding of the relevant concepts in 2013. Most of them could describe their understanding with the images captured and the correct annotations. Specifically, through analysing the

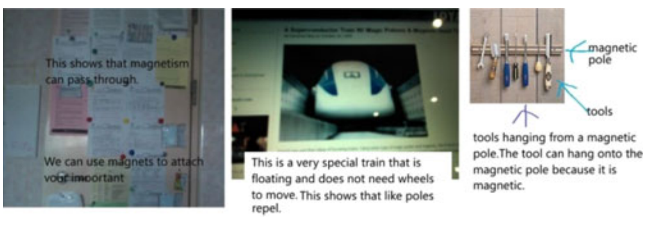


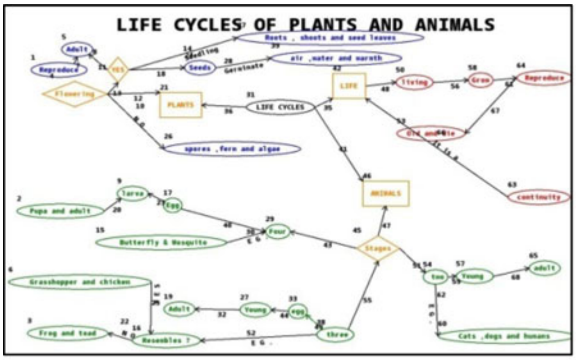
Fig. 6. Students' Sketchbook artifacts of magnets in their daily lives.

topics and their specific tasks, we found that students actively participated in doing and recording the scientific phenomena (e.g., phone camera and Sketchbook) in the experiments occurred out of the classroom, such as observing the growth of beans, the life cycles of mealworm, and the growth of mould in moist bread. Most students managed to capture the process of these phenomena. Based on these observations, we suggest that the students have developed more interests in observing scientific phenomena in daily life and intended to explain the phenomena observed by applying the new concepts and principles learnt in M5ESC. Our classroom observation provided further evidence to demonstrate such positive changes. In the classroom, students were interested in teachers' comments on their artifacts and would like to share their learning process behind their work with the class and the teacher.

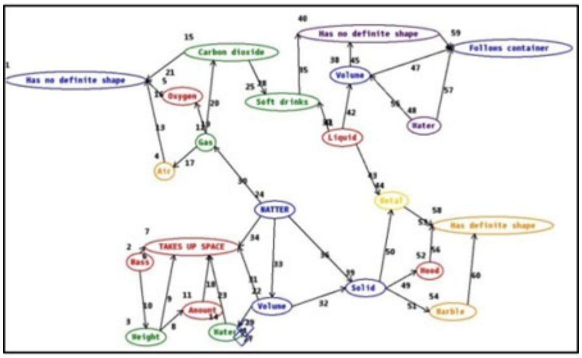
MapIT concept maps. A concept map represents a collection of interconnected concepts with specified relationships between pairs of concepts on the links connecting them [37]. Concept maps are not only identified as effective learning tools but also as evaluation tools for encouraging students to use meaningful-mode learning patterns [38]. Through reviewing students' concept maps, teachers could obtain full information about students' conceptual understanding and detect their misconceptions. In M5ESC, MapIT activities were designed for both 2012 and 2013 science topics with the aim to develop students' system thinking of what they learnt and how each concept was related to each other. Based on literature review [39], [40]), we identified three levels of concept maps, which were used to evaluate the quality level of students' MapIT learning artifacts.

- *Low quality*. Presenting a part of key concepts without relationship links;
- Middle quality. Presenting a part of key concepts with a part of correct relationship links;
- High quality. Presenting all key concepts with correct relationship links.

From the review of students' concept maps drawn using MapIT, we found students had developed slightly better skills at constructing concept maps with increasing participation in M5ESC. The total number of concept maps constructed was 73 and 110 respectively in 2012 and 2013. Fig. 7 shows the progression of the quality level of concept maps generated by students. Students constructed more middle and high quality concept maps than they did in 2012. Specifically, the rate of high level concept maps produced increased from 33.01 percent in 2012 to 39.35 percent in 2013. The rate of low level concept maps generated decreased from 8.23 percent in 2012 to 0.2 percent in 2013. The result revealed students' progress in doing MapIT



(a)



(b)

Fig. 8. (a) Concept map in topic of Life Cycles. (b) Concept map in topic of Matter.

activities, although the progression was not as significant as that in Sketchbook activities.

A considerable number of students intended to present their understanding of the target concepts via drawing complex concepts and organizing the key concepts together with correct relationship cross-links. Student improvement in 2013 suggested it was possible to develop students' system thinking skills in lower primary grades. We selected some good examples (high quality level) of students' responses to the MapIT tasks from the topic of life cycles and matter (Fig. 8). Fig. 8a represents a student's understanding of life cycles of plants and animals. It generally presents students' thinking of the classification of animals and plants, and the key phases of their life cycles. All these covered key concepts they learnt in the classroom. Fig. 8b also represents a student's understanding of the classification of materials and the properties of these materials.

6.3 Students' Classroom Performance

Being equipped with smartphones, we found that students participated actively in sharing and discussing the learning artifacts, collecting data in the experiments, and interacting with teachers compared to the traditional science class. In M5ESC, to promote students' engagement in the collaborative activities in the classroom, students were encouraged to share their learning artifacts with their partners or the class. Few of students could take the initiative in presenting their work and discussing with their classmates or the teacher at the beginning stage, while after a certain period of implementation, most students became more comfortable when their teacher presented their work via projector on the white

(a). Group discussion (b). Collaborative work

Fig. 9. Students' interactions arising from their work on the smartphones.

board. They interacted more frequently with the teacher to share their reasoning and thinking. This was very different from the situation in 2012 when students had considerable concerns about receiving the negative comments from the teacher and their classmates. Using exploratory questioning in the M5ESC classroom, teachers provided more space for students to think, reflect and explain by themselves instead of providing comments directly to the students [41]. Influenced by the open questioning learning environment, students' participation in classroom sharing and discussion was promoted, which in turn contributed to the positive changes in their learning performance [42]. This also connected students work done out of the classroom with their thinking and learning in the classroom. As Fig. 9a shows, students gathered to share their information searched from the Internet and to discuss their understanding with their group members.

At the later stage, students had better understanding of the value of the smartphones for searching online information and collecting data in experiments. When collaborating with their partners in experimentation, they gradually developed the habit of using smartphones to document the experiment done by their partners by taking videos or pictures. As we can see in Fig. 9b, when the girl was doing the experiment, her partner used his phone to record the phenomenon, discussed the procedures on how to do it and applied relevant knowledge on explaining the phenomenon. This pattern of collaboration was common in the classroom, as well as in the field trips and other out-of-classroom group activities in M5ESC lessons.

7 Conclusion and Implications

This study presents findings from a sustained seamless learning project in a primary school that aims to develop and implement an innovative curriculum supported by mobile technologies for primary science learning. The research design was guided by two research questions concerning the design of the pedagogical principles for mobile learning and its educational value for improving students' science learning. Franklin identified three complexities that mobile learning brings to the educational area: pedagogy, communication and infrastructure [13]. In mobile learning, pedagogy has been the major issue on the innovation design and implementation as we mentioned in the literature review. Consequently, in complementing current studies on mobile learning, the paper first provides the theoretical foundations on how the seamless learning program was established and how it was integrated into a standards-based science curriculum. In our mobile learning design of M5ESC, we attempted to design the appropriate learning activities at the different cognitive levels for the needs of different ability students (the feature of seamless: adaptivity). We emphasized the connection between mobile activities out of the classroom and learning in the classroom (the feature of seamless: connectivity) [43].

The design principles for knowledge construction are proposed to improve the pedagogical design of mobile learning. The design of activities at different cognitive levels narrows the gap between the purpose of research design and school-based curriculum design. The second research question was answered by examining students' achievements in their science test results, their involvement in the mobile learning activities, the quality of mobile learning artifacts they generated using the mobile learning tools, as well as their activity performance in the classroom in the context of M5ESC. Researchers have pointed out that the dearth of research on large-scale and sustained deployment of mobile learning, and the loss or compromise of the unique attributes of mobile learning [44]. There is little research that has managed to trace the yearly progression of students' performance in mobile learning with the combination of quantitative and qualitative data at scale. Our study attempts to fill in this gap. The cross-year comparison of students' academic achievements, mobile learning artifacts and their activity performance provides valuable information on how to evaluate the outcomes and processes of mobile learning.

Data analysis shows that students gained significant improvement in their test achievements; they became more engaged in the mobile learning activities with increased participation and improved work quality. Among these activities, students participated more in KWL, Sketchbook and MapIT tasks. The increased KWL participation also reflected the teachers' efforts on assessing and commenting on students' reflection of their conceptual understanding. Encouraged by the feedback from the teacher, these students generated more positive KWL work when they were in P4. Meanwhile, students' active participation in the sharing and collaborative work further verified their progression. In conclusion, an inquiry-based seamless learning innovation would have educational value on science learning when the innovation was well-designed by appropriate pedagogical principles and implemented in an iterative way [45], [46]. However, a weakness of the study is the lack of a control group that would enable further investigations of how students' normal cognitive development might also have contributed to these progressions. The absence of a control group is due to the innovation being scaled up to the whole P3 and P4 grade levels in the pilot school.

This research can inform the pedagogical design of mobile learning, as well as the research design of studies on mobile technology-supported curriculum. Early research has highlighted that the intensive use of technology does not mean the achievement of meaningful learning, and now the research focus has been shifted to the pedagogical design of technology-supported learning. Thus, in mobile learning design, the developers and practitioners should focus on the integration of mobile technology into the normal lessons and connecting the purposes of activity design with the learning objectives prescribed in the syllabus.

To leverage the affordances of the mobile technology, appropriate activity design is proposed for supporting seamless, ubiquitous, and contextual learning. Student learning and thinking will not only take place in one location or in a fixed time. They are open to do inquiry in more locations and in more flexible time frames. Drawing on the findings of our case report, for teachers in mobile learning, the critical factor for success is not on assessing the results of students' in and out of classroom tasks, but on the use of pedagogical approaches that connect the tasks and knowledge in and out of the classroom, the facilitation of students' work constructed by different learning tools, and the elaboration of understanding as revealed in their artifacts created using the mobile learning tools. For the researchers, the evaluation of students' performance should not depend heavily on students' self-reports. Researchers are encouraged to explore students' performance both in and out of the classroom and to study the evidence arising from practice in a sustained and longer term basis. Such efforts will contribute to the research involving the use of ubiquitous mobile technologies.

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