How Do Students Progress in a Mobilized Inquiry Science Curriculum

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Abstract: There is abundant research reporting the designs of ubiquitous and seamless learning environments which are enabled by the integration of mobile technology. However, the lack of pedagogical designs that provide for sustainability, and the inadequate investigations of learning outcomes are some of the major gaps in current studies. Towards addressing these issues, this paper describes a study that illuminates the principles of how mobile learning can be integrated into a standard-based science curriculum, and explores how this mobilized curriculum impacts students' performances in and out of the classroom. Data analysis on students' test results, learning artifacts and their activity performances in the classroom suggested that they improved in conceptual understanding and self-reflections on conceptual changes. Students were engaged in mobile learning activities both and out of the classroom based on sustained exposure to and experiences of the mobilized science curriculum.

Keywords: Mobile Learning, Pedagogical Design, Science Curriculum, Conceptual Understanding

1. Introduction

With advances in smartphone technology, the use of smartphone has become pervasive and ubiquitous in many modern societies. Recognizing the multiple functions of the smartphone and its educational value, educators have long advocated the adoption of mobile learning in schools (Ng & Nicholas, 2013; Song, 2014). 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 obtaining evidence of student learning in mobile learning (Looi, et al, 2014). 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 at the curriculum level on student learning performance. The existing evidence is too scarce to inform future research and practices concerning mobilized school-based teaching and learning. Thus, it is necessary and significant to conduct a longitudinal study that develops pedagogical design principles on how to integrate mobile learning into a standardized science curriculum, and that traces the trajectory of students' performance progression throughout the learning process. This paper presents such a study focusing on exploring student performance change brought about by a mobilized science curriculum. The principles of integrating mobile learning into the standardized science curriculum will be introduced, and the findings of students learning performance in mobile learning activities will be reported and discussed. Implications will be drawn to inform the design and implementation of mobile learning.

2. Literature Review

In addition to the integration of suitable mobile technologies, how to combine appropriate pedagogical strategies for enhanced learning application has been a critical issue in mobile learning research (Jeng, et al., 2010). It has been extensively discussed that the design of mobile learning activities should be, like the design of any other learning activity, driven by specific learning objectives (Sharples, et al., 2009). 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 technology integration in science learning: in-class questioning, out-of class field trip observation, on site reflection, hands-on experimentation, and learning artefact creation, and sharing and evaluation (Song, Wong & Looi, 2012). Relevant studies on ThinknLearn, Mobile Plant Learning System, Mobile Tour System, and nQuire generated positive impact on both teachers and students, and highlighted the integration of appropriate pedagogical principles supported by technology design (Ahmed & Parsons, 2013; Jones, Scanlon, &Clough, 2013; Huang, Lin, & Chang, 201; Ruchter, Bernhard, & Geiger, 2010;). 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 and appropriate pedagogical approaches (e.g. inquiry-based principles, knowledge building, collaborating learning) can create special educational value for students' science learning.

Studies that discussed 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 abound. Yet none of these studies are directly related to the use of mobile phones for academic purposes (Lee, 2013). Sustainable mobile learning programs that are designed for teaching and learning standardized curriculum are rare. To further improve the educational use of mobile technologies, efforts should be made to align and integrate school curriculum into the research design, and thus to improve the balance between research needs and school needs. Moreover, recent mobile learning research emphasizes more on learning in the informal context. Few studies have designed mobile activities that connect learning in both formal and informal contexts. Evidence about the integrated and synergetic effects of linking these two contexts or environments of learning is inadequate (Looi, et al., 2010). 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). Fewer 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 standard-based science curriculum supported by mobile learning, and explored how this innovation has 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' performances 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 standard-based science curriculum?
2. What are students' learning progressions in and out of classroom impacted by the mobilized curriculum?

4. Introduction of M5ESC

4.1 M5ESC and MyDesk Learning System

In our project, an innovative science curriculum, namely, Mobilized 5E Science Curriculum has been developed iteratively and progressively via design-based research in Singapore since 2008 (Looi, et al, 2009). It is a first attempt to systematically and comprehensively explore the integration of mobile learning with a science curriculum for long-term, stage-by-stage intervention. The curriculum is mapped to national science curriculum standards, and covers all of the standard materials required in a primary school. Aligning with the Primary Science Syllabus (MOE, 2008, pp. 2-3) and Singapore Ministry of Education (MOE)'s advocacy 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, reflective thinking skills) (Sha, et al., 2012; MOE, 2010). The lesson design of M5ESC is based on 5E (Engagement-Exploration- Explanation-Elaboration- Evaluation) inquiry principle (Bybee, 2006). It flexibly incorporates mobile apps from a learning system, MyDesk which is a multifunctional tool installed in windows smart phones. The system consists of a teacher module and a student module. Teacher module provides an authoring tool for the teacher to create mobile activities using different learning tools. It also supports teachers to review, evaluate and retrieve students' learning artifacts after lessons. In the student module, students can access the activities designed by their teacher, construct learning artifacts, and compose self-reflections using the assigned learning tools. The learning tools in MyDesk include KWL (doing self-reflection through responding to "what I **K**now" and "**W**hat I want to know" before and to "what I **L**earnt" after learning the topic), NotePad (taking notes), Recorder (recording voice), Sketchbook (drawing models), MapIT (constructing concept maps), and Blurb (posing questions). The combination of these tools 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 (Brooks & Brooks, 2009; Greca & Moreira, 2000). 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 will receive the teacher's rating of and feedback to their learning artifacts once their teacher has done the evaluation.

4.2 Design Principles of Mobile Learning in M5ESC

The designed mobile learning activities aim to fully leverage technological affordances both in and out of classroom, to address different cognitive levels of usage, and to provide the opportunity for teachers to create ubiquitous learning environment that brings together real-world resources and digital world information. Following Starkey's 'Digital Age Learning Matrix' (Starkey, 2011), we propose ways of integrating mobile technology into the standard-based curriculum (Table 1). The main purpose of applying mobile activities is facilitating knowledge construction, as well as developing science inquiry skills.

Level 1 mobile learning 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. Level 2, 3 and 4). As an animation tool, Sketchbook is used to promote students' ability to connect knowledge with daily experiences, and to develop higher levels of conceptual understanding (i.e. Level 5 and 6) through peer assessment of artifacts. Blurb is generally used to improve 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.

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	√					

The design of M5ESC is aligned with the vision that learning needs to be learner-centered, situated, collaborative, ubiquitous, and continuous. The use of technology has become more personalized, user-centered, mobile, networked, ubiquitous, and durable in M5ESC (Motiwalla, 2007). The incorporation of different tools facilitates blended forms of different learning activities residing in one learning environment (Naismith, et al., 2004). In the M5ESC classroom, the constructivist learning theory supports inquiry by placing the focus of learning on student ideas, questions, and understanding, rather than on teacher delivery of content (Fosnot, 1996). Thus, 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, student learning activities can be conducted both in and out of classroom according to the principles of seamless learning (Wong & Looi, 2011); Various patterns of learning activities (e.g. individual inquiry, collaborative inquiry, 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. In M5ESC, a substantial amount of time is allocated to doing the mobile learning activities as compared with non-mobile activities. Teachers and students interact more frequently in the discussion and sharing of work generated by mobile tools. As 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, students' performance in mobile learning activities, which represent their involvement in the learning process, is identified as an important indicator for assessing their learning gains in M5ESC. In this paper, our focus will be on students' performance both in and out of classroom with the intention of identifying students' progression in the mobile learning activities throughout the long-term intervention.

5. Participants

In the year of 2012, M5ESC was scaled at the whole Grade 3 level in a primary school (P3) in Singapore. The 2012 P3 cohort, 299 Students (aged 10-11) in 8 classes, were participants of this study. The cohort progressed into P4 in 2013. 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 classroom. There were 4 teachers teaching the P3 cohort, each in charge of two classes. Since the academic year of 2012, teachers and researchers worked together on a weekly basis to co-design and elaborate the lessons. All teachers performed actively in PD sharing and discussion in weekly teacher-researcher meetings. They had strong willingness to receive feedback on curriculum enactment and to elaborate their teaching strategies. Students and their parents also appreciated the educational value of the smartphone. The parents supported their children to use the smartphone out of the classroom to extend their learning.

6. Data Sources and Analysis

In this project, data collection focused on teacher performance in curriculum enactment, student performance in and out of classroom, and teacher and student responses in MyDesk. Classroom observation was conducted in each class in 2012 and 2013 throughout the whole school year. Field notes were used to record the lesson sequence and key instructional events in the class (i.e. questions, interaction, experiments, and mobile activities); 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 performance (i.e. engagement, concept understanding, reflective thinking) out of classroom. In this study, three sources of data were used for analyzing the progression of students' learning performance:

1) SA1 and SA2 results: students' achievement in standard tests. SA1 (Semestral Assessment 1 administered at the end of the first semester) and SA2 (Semestral Assessment 2 administered at the end of the second semester) scores in 2012 and 2013 were compared to provide more evidence for supporting our research hypothesis that students would benefit more in reasoning and conceptual understanding with the implementation of M5ESC. 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 to evaluate students' progress over the year. The total score of SA1 and SA2 was 100 marks, with 60 marks for MCQ (Multi-Choice Questions) (2 marks for each item) and 40 marks for OEQ (Open-Ended Questions) (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 level of SA1 and SA2 are comparable at the item level. To investigate 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.
2) MyDesk work: work completion rate and level of work quality. A cross-year comparative study was conducted to uncover students' progression in MyDesk performance. The completion rate of each task was analyzed to investigate students' engagement in mobile learning activities that

occurred out of classroom. The quality level of work produced in KWL, Sketchbook, and MapIT, 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

3) Students' activity performance in the classroom: student performance in sharing, discussion, and experimentation.

Data analysis was conducted by two researchers, and the inter-rate agreement of MyDesk coding reached 93%.

7. Findings

7.1 Progression in Academic Performance

One-sample t-test (Table 2) was conducted to compare 2012 and 2013 P3 SA1 and SA2 results. The result showed that the whole P3 cohort made a significant increase of 7.69% in total score from SA1 to SA2 ($t = 6.584$, $p < .05$) in 2012. In 2013, the improvement (10.07%) was also significant ($t = 13.626$, $p < .05$). In 2012, it was prominent to note that such progress was mainly attributed to their increase in OEQ scores (27.04%) ($t = 11.845$, $p < .05$) since they experienced a slight (not significant) decrease in MCQ scores. After getting into the second scaling year, P4 students performed as well as the previous P3 students in 2012 in MCQ (6.91%) and OEQ (20.33%).

Table 2. SA1/SA2 HA-MA-LA[1] Gains in 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

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

Specifically, in 2012, the LA group out of the three ability groups, achieved the highest MCQ gains (13.16%) ($t = 2.487$, $p < .05$), OEQ gains (60.30%) ($t = 7.071$, $p < .05$) and total gains (23.49%) ($t = 4.809$, $p < .05$). Additionally, the HA group achieved significant OEQ gains (11.71%) ($t = 7.798$, $p < .05$) and the MA group achieved significant OEQ gains (29.55%) ($t = 8.835$, $p < .05$). In 2013, the three ability groups (HA, MA and LA), achieved equal gain. Our analysis showed that most classes had a significant increase from SA1 to SA2 in terms of MCQ scores, OE scores and total scores, except the LA group who did not achieve significant increase in MCQ gains.

In summary, both 2012 and 2013 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 MA group, especially in OEQ scores.

7.2 Progression in Mobile Learning Performance

7.2.1 Students' Engagement in MyDesk learning activities

In 2012 P3, 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 3 shows the results of the average completion rate of these activities using the assigned learning tools in 2012 and 2013. The result suggested that students provided more responses to these mobile activities in 2013/P4 (with an average completion rate of 44.85%) than they did in 2012/P3 (with an average completion rate of 24.09%). Compared to 2012 MyDesk task completion, students in 2013 achieved a high completion rate in KWL, MapIT and Sketchbook activities. In Sketchbook activities, the response rate increased more than 50%. This revealed that students were more engaged in using Sketchbook to describe their understanding and to relate their understanding with their daily life experiences.

Table 3. The comparison of MyDesk activity completion rates in 2012 and 2013

Year	Audio	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%

Paired samples t test indicated the significant difference in usage between different learning tools in 2012, such as between audio 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 also found between KWL and MapIT, and MapIT and Sketchbook. This suggested students' discrepant involvement in different mobile learning activities out of 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. This also provided valuable information for teachers to improve their design, elaboration, and evaluation of the mobile learning activities for students.

7.2.2 Progression in conceptual understanding

We selected students' artifacts in KWL, MapIT, and Sketchbook (which received higher completion rates) to compare the quality level of the MyDesk work done in 2012 and 2013.

1) 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;
- 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 the lessons;
- What I **learnt -** refers to student's self-reflection on the knowledge he/she has learnt about the assigned topic after the lessons.

Data analysis of students' work in KWL in 2012 and 2013 suggested that students not only performed more actively in responding to KWL activities, but also improved their levels of reflective thinking. Compared to the 24.08% completion rate of What I Learnt in 2012, the completion rate of 2013 (which was 41.43%) was high. Moreover, students became more willing to share their prior knowledge (the completion rate of What I Know increased from 33.83% to 56.43%). In 2012, only 20% students completed all the three sections of KWL. In 2013, that figure was doubled (40%). 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. They had gradually developed their thinking skills as they got into P4. They also become more skilful at reflecting their knowledge understanding.

2) 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 were designed for students to observe and record the growth of plants, the lifecycle of mealworm, and the comparison between moist and dry bread. In P3, Sketchbook activities were designed to provide students extensive opportunities to explore the name, properties and value of materials, fungi, heat, and magnets in the surrounding environment. We coded Sketchbook activities into four quality levels modified from the knowledge integration scoring rubric (Linn & Eylon, 2011):

- 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.

Having analyzed the completed Sketchbook activities, 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. Figure 1 shows the distribution of the quality levels of students' Sketchbook learning artifacts.

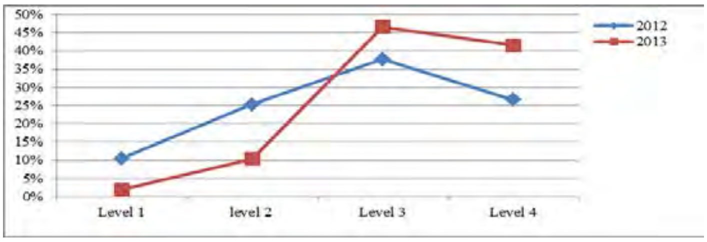

Figure 1. Distribution of the quality levels of Sketchbook activities

Compared to their 2012 performance, students performed well in Sketchbook activities in 2013The proportion of L3 and L4 artifacts, the high level ones, had increased from 37.68% to 46.53%, and from 26.55% to 41.43% respectively. Meanwhile, the decrease of L1 and L2 work further suggested students' progression in Sketchbook activities. Another interesting finding was students' active participation in doing and recording experiments occurred out of classroom, such as observing the growth of beans, the life cycles of mealworm, and the growth of mould in moist bread. We could summarize that students had developed more interest 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 for the demonstration of such positive changes. In the classroom, they were more interested in elaborating the artifacts, and would like to share their learning process behind their work with the class and the teacher.

3) MapIT Concept Map

Through reviewing students' concept maps, teachers could obtain full information on the levels of students' conceptual understanding and detect their major 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 related to each other. Based on literature review (Kinchin, et al., 2000; Slotte & Lonka, 1999), 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

Reviewing students' concept maps drawn using MapIT, we found students had developed better skills at constructing concept maps with increasing participation in M5SCE. The rate of high level concept maps produced increased from33.01% in 2012 to 39.35% in 2013. The rate of low level concept maps generated decreased from 8.23% in 2012 to 0.2% in 2013. A considerable number of students intended to present their understanding of the target concepts via drawing complex concepts, or organizing the key concepts together with correct relationship links. The improvement in 2013 suggested that it was possible to develop system thinking skills in students in lower primary grades.

7.3 Students' Classroom Performance

Being equipped with smart phones, students performed actively in sharing and discussing the learning artifacts, collecting data in the experiments, and interacting with teachers. 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. At the later stage of M5ESC implementation, most students became more comfortable when their teacher presented their work via projector on the white 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 negative comments from the teacher and their classmates. Using exploratory questioning in the M5ESC classroom, the teacher provided more space for the students to think, reflect and explain by themselves instead of providing comments directly to the students (Kerawalla, Marilena, & Scanlon, 2013). Hence, influenced by the open questioning learning environments, students' participation in classroom sharing and discussion was promoted, which in turn contributed to the positive changes in their learning performance. At the later stage, students had better understanding of the value of the smartphone for searching online information and collecting data during experiments. When collaborating with their partners in experimentation, they gradually developed the habit of using smart phones to document the experiment by making videos or taking pictures. As we observed, when one student was doing the experiment, her/his partner would use the phone to record the phenomenon. This pattern of collaboration was common in the M5ESC classroom, as well as in the field trips and other out-of-classroom group activities.

8. Conclusion

This study presents findings from a sustained seamless learning project in a primary school. 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. 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 standard-based science curriculum. The mobile learning design for knowledge construction is 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 the needs of school-based curriculum design.

Researchers have pointed out that the dearth of research in any large-scale and sustained deployment of mobile learning, and the extent to which the unique attributes of mobile learning may be lost or compromised (Traxler, 2007). 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 bridge this gap. The cross-year comparison of students' academic achievements, mobile learning artifacts and their activity performance provide valuable information on how to evaluate the outcomes and processes of mobile learning and how to encourage the practitioners to buy-in, sustain, and scale the curriculum innovation. The findings indicate that students could benefit from the mobile learning when it was pedagogically integrated with the standardized science curriculum.

This research can inform the pedagogical design of mobile learning, as well as research design of studies on ICT-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 ICT-supported learning design, the developers and practitioners should focus on the integration of ICT into routine lessons and on linking the purpose of activity design with the learning objectives as prescribed in the syllabus. 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 classroom and to study the evidence arising from their practices. Such efforts will contribute to the research in technology-supported learning, especially involving the use of ubiquitous mobile technologies.

Acknowledgements

The paper is a part of work from project "Bridging Formal and Informal Learning Spaces for Self-directed & Collaborative Inquiry Learning in Science" funded by Singapore National Research Foundation (NRF2011 - EDU002-EL005). We would like to thank our other team members Gean Chia and Peter Seow, and teachers and their students from Nan Chiau Primary School for working and collaborating on this project.

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