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Implementing mobile learning curricula in a grade level: Empirical study of learning effectiveness at scale

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A B S T R A C T

Developing and then scaling up an educational innovation so that it achieves on the dimensions of depth, sustainability, spread and change of ownership is a complex endeavor. In this paper, we present a study of one such innovation which has been developed through a design-based research process in a Singapore school. The innovation features a primary science curriculum integrating the 5E inquiry phases with the use of mobile technology. It has evolved through the various development phases to where the innovation is becoming an integral part of routine classroom practices. With the objective of examining the impact of the curriculum innovation on science teaching and learning, this paper reports some of the results of our scaling efforts, in particular, those relating to changes in classroom practices and the effectiveness brought by the curriculum innovation. Using qualitative data analysis methods, the study discusses the transformation of the classroom practices on teachers' pedagogical approaches, classroom culture, lesson plan design, linkages to informal learning, assessment methods, and parent involvement. Quantitative analysis of the performance of students in science assessments when compared between pre-scaling and scaling phases shows the efficacy of the innovation when scaled up to a whole grade level. Implications are drawn to inform future studies or work on factors for effective scaling up of technology-supported curricular innovations.

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1. Introduction

Nowadays, with technological advances in both hardware and software, the increasingly pervasive and ubiquitous nature of mobile technology has been recognized by many researchers and educators from the school perspective (Avraamidou, 2008; Mulholland et al., 2012). The literature cites research efforts devoted to developing mobile learning projects or curriculum which integrates mobile technology with appropriate pedagogy for supporting students' science learning in both formal and informal settings (Ahmed & Parsons, 2013; Looi et al., 2011; Song, Wong, & Looi, 2012). With mobile technology, science inquiry can be extended into more authentic contexts, such as field trips to a park, woodlands, and a museum, and other home-based activities. Such designs seek to establish connections between the acquisition of new knowledge in the classroom and the application of the knowledge outside of the classroom, and teachers' formative assessment can become more flexible and in-time (Merchant, 2012).

However, the research literature has also indicated that most studies of mobile learning are just pilot projects or proofs-of-concept that tended to focus on effectiveness studies, surveys and experiments or the designs of the mobile learning system (Wu et al., 2012). It is rarer to see a mobile learning project move through the various phases to where the innovation actually has become an integral part of routine classroom practices. There are also few studies that conceptualize sustainable learning with mobile technologies via immersion into the standard curriculum, especially in the domain of science education. There is a need to conduct longitudinal studies on tracing the learning effectiveness based on sustainable and long-term interventions.

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On the policy perspective, in the context of Singapore, the initiative of the government's third Masterplan (mp3) for ICT in Education (MoE, 2013) provides a policy imperative for schools to conduct sustainable curricular innovations for better use of the ICT in teaching practices. The emphasis is on integrating ICT into the curriculum through developing new pedagogy and assessment; for cultivating the competencies for the 21st century; for developing practice-based professional development models for teachers' better adaptation of the ICT-supported curriculum; and for improving the sharing of best practices and successful innovations. In this context, our work places a strong emphasis on how to integrate the mobile learning into the standard science curriculum and how to scale this curriculum into more grade levels and schools in Singapore. Moreover, educational researchers have pointed to the need to examine reform efforts systemically to understand the pathways and impediments to successful reform (Anderson & Helms, 2001). Thus, presenting the process and results of a curricular innovation can help unfurl the vivid map of the developmental trajectory of a curricular innovation, and provide evidence for the effectiveness of the curriculum implementation.

In our collaboration work with a primary school in Singapore over five years, we have developed such a viable curricular innovation model, namely a Mobilized 5E (Engagement → Exploration → Explanation → Elaboration → Evaluation) Science Curriculum (or M5ESC in short). The innovation involves the transformation of the existing national science curriculum into one with an inquiry-based orientation which leverages the affordances of mobile technologies (i.e. smartphones). It seeks to systematically and comprehensively integrate the mobile technologies into the national science curriculum at the primary level. In this paper, we describe this scale-up research of the curricular innovation, with a focus on the demonstration of its effectiveness when it is used in a routine and sustained manner, and deployed on at whole grade level. This study is guided by two research questions:

(1) How to develop and scale up an innovative inquiry-based science curriculum supported by mobile technology?
(2) What are the changes in classroom practices and students' performances brought about by the scaled-up curricular innovation?

This paper is organized as follows: we first discuss the literature for mobile learning in science education and for the scaling-up of evidence-based practices. We provide the contextual information of the M5ESC development and then narrate its scaling process. We next analyze data on changes in classroom practices as well as the perspectives of teachers who implemented M5ESC in their classes. For probing the effectiveness for students' science learning, we explore the students' performances based on the yearly comparison of their science test achievements during the years of scaling with the years of pre-scaling. The findings are discussed and implications drawn for informing relevant studies on technology-supported curriculum development and implementation.

2. Literature review

2.1. Mobile learning in science education

With mobile technology, the science learning environment can be mobile and go with the students to the field site, to the laboratory and beyond (Martin & Ertzberger, 2013). The extension of the learning environment enables students to investigate more science phenomena in real life and to demonstrate principles and scientific knowledge in different contexts other than the laboratory (Shih, Chuang, & Hwang, 2010). Furthermore, the social networking opens up opportunities for students to do socially-mediated knowledge-building associated with learning science by doing science at anytime and anywhere. Science projects with the use of mobile technology have demonstrated the merits of mobile learning and its learning effectiveness for students (Pea & Maldonado, 2006).

From our reviews of the studies on mobile technology-supported learning, we found that most of them focused on investigating the learning effectiveness from deploying specific pedagogical principles in the mobile learning activities. Ahmed and Parsons' (2013) study focused on using a mobile learning system ThinknLearn for supporting students' abductive science inquiry in the process of exploration, examination, selection and explanation. The findings suggested that with mobile learning, students improved in their skills on generating hypotheses and in developing critical thinking skills. In another study, a mobile plant learning system (MPLS) installed in PADs was used for supporting students outdoor investigation of plants through the ways of searching, creating and sharing the knowledge of plants. The study revealed that the MPLS helped students to acquire knowledge and stimulate their motivation and enthusiasm on engaging in outdoor mobile learning, as well as in social interaction and discussion about the course materials (Huang, Lin, & Chang, 2010). In Ruchter, Bernhard and Geigers' study on the investigation of mobile computers in environmental education, the mobile tour system boosted student's learning about environmental literacy as well as their learning attitudes and motivation (Ruchter, Bernhard, & Geiger, 2010). Song et al. (2012) proposed a goal-based approach to design a mobilized curriculum to guide students' personalized inquiry learning in primary science. The approach has been verified with evidence that showed students' acquiring scientific knowledge and developing self-directed learning skills. These studies collectively point towards the particular role that mobile learning can play in science education, and that the combination of mobile learning system/apps and the appropriate pedagogical approaches (e.g. inquiry-based principles) could have special educational value for students' science learning related to their knowledge, skills, competences, and attitudes.

However, the current studies most focus on creating learning environments for leveraging the affordances of mobile technologies, focus only on units of at most a few weeks duration or they were add-on activities to some existing curriculum (Ng & Nicholas, 2013). The learning experiences of mobile technology-supported learning activities were short-term in nature. There is no research that considers conceptualizing sustainable learning with mobile technologies via immersion into the national standard science curriculum for sustainable and scalable purposes. Thus, little attention has been put on to trace the trajectory of the transformation of teacher and students behaviors impacted by the long term innovation. Thus, no evidence has been produced to inform the relevant studies relative to the mobile technology use in the science classroom at scaled-up levels. To address these issues, our study reviews the journey of the development of an innovative science curriculum, captures the turning points of the transformation at different development stages, and presents the evidence on how the transformation took place and whether and how students could benefit both in content knowledge and skills at scale.

2.2. Scaling-up evidence-based practices

Fullan, Cuttress, and Kilcher (2005) pointed out that understanding the change process is a big driver in the educational reform because such understanding of the change process is about establishing the conditions for continuous improvement in order to persist and overcome inevitable barriers to reform. The evidence-based practices serve the purpose of gathering evidences from a staged-based curriculum innovation to establishing the connection between consecutive stages. The evidence captured is especially beneficial to practitioners for understanding the change process of the curriculum reform and for assisting them to implement the innovation. Scaling-up evidence-based practices is the process in which researchers and practitioners initially co-design and implement innovations or interventions on a small scale, validate them, and then implement them more widely in broader contexts (Klingner, Boardman, & McMaster, 2013).

Dunlap, Sugai, Lewis, Goodman and Horner (2009) delineate four phases of implementation when scaling up an evidence-based practice: (a) emergence, (b) demonstration of capacity, (c) elaboration, and (d) system adoption and sustainability. Emergence happens when the school leaders in consultation with the developers of the curriculum decided that it might actually be scalable. In the demonstration phase, researchers determine whether the practice is feasible and whether it has a significant effect on target outcomes. With the elaboration phase, the teachers implement the practice more broadly, drawing on the lessons learned during the demonstration phase and building on the capacity of the school leaders to implement the practice. In the final phase of system adoption and sustainability, the practices are integrated into the normal routines of the school so that they continue over time. These conceptual lenses pave the ways for the scaling of the curricular innovation based on the evidence from the learning and teaching practices that resulted.

The development and scaling of M5ESC went through two stages: Pre-scaling phase (year of 2009[1] and 2010, and 2011) and scaling phase (year of 2012 and 2013). In 2009, we worked with one experimental class in P3 ($n = 44$) taught by a science teacher Jodie who had six-year teaching experience in science for implementing mobile curriculum to replace the traditional curriculum. In 2010, we continued our research by working with this same class who had by then moved up to P4. Particularly, our design was not just integrated as a project or activity in the class, but as a curriculum contained all topics in P3 and P4 science and harmonized with the science syllabus, classroom realities (student needs, student–teacher relationships, school culture, and textbooks) (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012), and followed the same class schedule and assessment schemes as the rest of the classes. Clearly changes have occurred in the experimental class and the teacher involved with evidences from research analysis (Looi et al., 2011; Zhang et al., 2010) during the two years of intervention,[2] and from interviews with the stakeholders (school leaders and teachers). With the mobilized lessons, we observed students engaging in science learning in personal and engaged ways, and they performed better than other classes as measured by traditional assessments in the science subject (Looi et al., 2011; Sha, Looi, Chen, Seow, & Wong, 2012). We also saw a shift in the teacher's attitudes and behaviors towards science teaching, from a style that saw her pre-occupied with just covering the curriculum to one that allows her to watch over and facilitate students' work on the inquiry activities on their handhelds.

When the curricular innovation using mobile devices has been co-developed and studied in the context of one class, and the empirical evaluation of the mobilized curriculum has shown its potential for learning effectiveness, the school leaders decided that it was a worthwhile innovation and, in consultation with the researchers and collaborators, would like to scale up the innovation. The evidences of efficacy provided support that the scaling-up of the curricular innovation was feasible and worthwhile. Thus, in the year of 2011, researchers and teachers discussed, reflected and elaborated the designed lessons for supporting the scaling of the curriculum at P3 at first, and also discussed the possible issues when the curriculum was scaled at the whole P3 level. Once prepared, the curriculum was scaled at all P3 classes in the year of 2012, which we identified as the demonstration phase of the innovation scaling. In this year, researchers, teachers and collaborators revised the M5ESC lesson plans and proposed the appropriate teaching strategies through conducting a series of teacher professional workshops and regular group meetings. Meanwhile, researchers were responsible for observing teachers and students performance both in and out of classroom for collecting evidence on classroom changes and demonstrating the learning effectiveness of the curriculum. The findings further suggested that students could demonstrate their understanding of science phenomenon in multimodal ways, do self-directed learning by mobile phones and peer discussion of their learning artefacts. They engaged in instructional activities that involved their parents their mobile learning activities. This lied in contrast to the more "traditional" way of learning, in which students learned science from the didactic instruction of the teacher or from the textbook (Andrew, 2007).

Year 2013 is the elaboration phase of the M5ESC scaling. More efforts were placed on teacher professional development, the elaboration of school-based worksheets and the linkages of informal learning with formal learning. This was the stage to deepen the use of intended pedagogical principles of the M5ESC in science class and to elaborate the lesson plans based on the problems and challenges identified during the curriculum implementation in 2012. The findings in the following sections will show the emphasis of the elaboration of M5ESC in the teaching practices. Finally, the evidences and the outcomes generated in 2013 will support the sustainability of the innovation in more grade levels. In summary, scaling-up of an innovation is a complex process. If the execution of each scaling activity proceeds in a stage by stage manner with design-based research providing the persuasive evidences, the innovation is more likely to be sustainable and scalable.

3. Context

3.1. The principles of M5ESC

As mentioned above, the M5ESC was developed by a design-based research approach with iterative research cycles over a period of five years (Penuel & Fishman, 2012). The basic rationale of the M5ESC that it is not feasible to equip students with all the skills and knowledge they need for lifelong learning solely through formal learning (or any other single learning space); henceforth, student learning should move

[1] The school academic year starts from January and ends in November of the year; thus it is straightforward to refer to the school year by the calendar year.

[2] During the curriculum implementation, PD sessions in the form of regular meetings were conducted for improving teacher's understanding of and skills in implementing M5ESC, as well as for transforming their pedagogical beliefs on the use of mobile technology. Meanwhile, the researchers sat in the classes and observed the teaching practices and learning activities so as to explore the gap between the desired curriculum and the enacted curriculum.

beyond the acquisition of content knowledge to develop the capacity to learn seamlessly (Chen, Seow, So, Toh, & Looi, 2010). The key epistemological design commitments of the curricular innovation are: learning as drawing connections between ideas, and learning as connecting science to everyday lives, across multiple learning spaces (such as between formal and informal learning settings, individual and social settings, and learning in physical and digital realms). The curricular commitment is seamless learning, and inquiry-based facilitation and learning. Concerning the curricular commitment, the Ministry of Education of Singapore has advocated teaching and learning science through inquiry and proposed the use of BSCS 5E Instructional Model in science learning (Bybee, 2002; CPDD, 2008). This 5Es model consists of the following phases: engagement (the access to know students prior knowledge and make them engaged in the science phenomena), exploration (the opportunities are provided for students to investigate the science phenomena or principles), explanation (students are encouraged to interpret their understandings of science phenomena and relevant principles or concepts'), elaboration (students' understanding of the phenomenon challenged and deepened through new experiences), and evaluation (students' understanding is assessed by appropriate assessment methods). Thus, each phase has a specific function and contributes to the teacher's coherent instruction and to the learners' formulation of a better understanding of scientific and technological knowledge, attitudes, and skills. Integrated with the mobile learning activities, the 5E inquiry is conducted in a seamless learning environment. In M5ESC, the technological commitments include: technology for construction, technology for communication, and technology for sharing anywhere anytime.

In M5ESC, MyDesk system that runs on a Microsoft Windows Mobile operating system is flexibly integrated with the 5E inquiry phases. With MyDesk Teacher Portal (Fig. 1a), the teachers create learning activities for the 5E inquiry-based lessons by employing multiple media and applications (e.g., text, graphical, spreadsheet, animations, and the like), and then review and comment students' work generated in the activities (Looi et al., 2009). Students can assess to the learning activities and complete their tasks using learning tools in the students module of MyDesk (Fig. 1b).

Table 1 depicts the learning tools and their functions, and the exemplar mobile learning activities in the lesson unit of Fungi at P3 science.

The combination of these tools with 5E inquiry activities is intended to facilitate students to develop sophisticated and systematic understanding of scientific concepts, enhance skills in modeling, reasoning and reflective thinking, especially to foster self-directed learning skills in and out of the classroom (Brooks & Brooks, 1993; Greca & Moreira, 2000). Other supporting tools are also incorporated (e.g., mobile blog, online discussion forum, video/photo camera, and a search engine). With these tools, students' prior knowledge and ideas must be accessed and addressed in order to build new and deeper scientific understandings through inquiry. Meanwhile, inquiry and other supportive constructivist practices foster meaningful science learning.

3.1.1. *The scaling of M5ESC*

In the academic years of 2012, all teachers of P3 (8 classes) participated in the PD workshops and regular PD meetings for elaborating and implementing the curriculum. Researchers provided extensive support in both the PD and teaching practices, seeking to maximize the educational value of M5ESC through collecting and then analyzing multiple data from the classroom sessions. To support better spread to all teachers and all classes in P3, the scale-up comprised these multiple dimensions of enablement which have been frequently discussed in the literature on curriculum reform or scaling (Davis, 2003; Fullan, 2002; Guzman & Nussbaum, 2009; Talbert, 2009).

- School leadership
- Teacher readiness
- Teacher facilitation skills
- Student readiness (e.g. hardware and software training of the mobile device, inquiry learning)
- Technology infrastructure (e.g. WiFi and 3G Connectivity; availability of mobile devices in 1:1, 24 × 7 basis)

In 2013, the innovation was adopted by all the P3 and P4 science teachers (P3 and P4) in our pilot school, teachers, researchers and collaborators were still working together on the elaboration of the curriculum. We are interested in establishing how the classroom teaching practices are sustained, what the teacher perspectives of their curriculum implementation are, and what the learning efficacies of these cohorts of students compared with those of previous years are. Different transformations could happen with a curricular innovation. In the context of M5ESC, the transformations mainly centered on the pedagogy, curriculum, technology integration, students' learning patterns, parent attitudes, teachers' attitudes, beliefs and capacities, and classroom culture. We have reported our findings on some of these transformations arising from the implementation of M5ESC (Looi, Sun, Seow, & Chia, 2014; Looi et al., 2009; Norris, Soloway, Tan, & Looi, 2013). In this paper, we will provide fresh data on students' learning outcomes and the analyses of classroom practices with the M5ESC

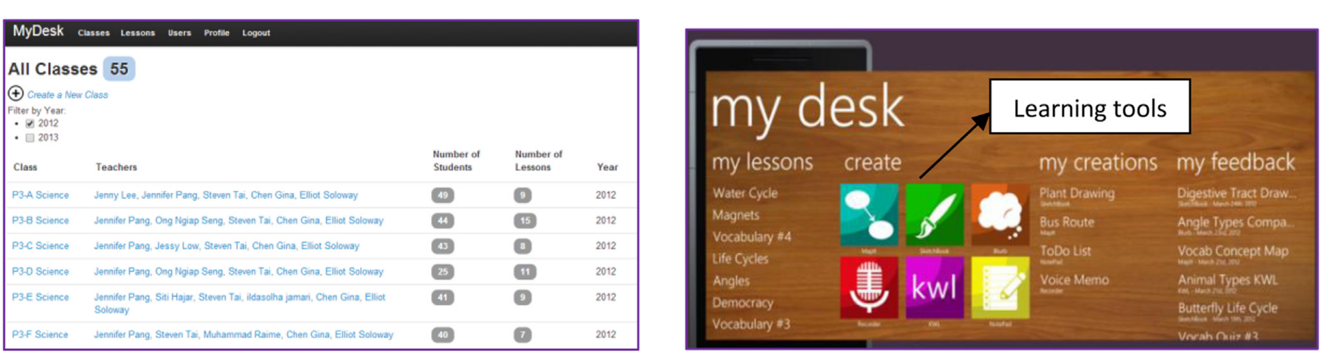

Fig. 1. a. The MyDesk Teacher Portal. b. Students module of MyDesk.

Table 1
The learning tools of MyDesk learning system.

Tools	Functions	Mobile activities in Fungi
(KWL)	• A self-reflection tool supporting students' reflecting upon on learning process and conceptual changes through responding questions (i.e. what do I already **K**now? what do I **W**ant to know? What have I **L**earned?) to allow students to learn in a self-regulated way.	• **Engagement:** students respond to "what do I already know" about fungi in KWL. • **Exploration:** students respond to "what do I want to know" about fungi in KWL. • **Evaluation:** students respond to "What I have learnt" about fungi in KWL.
(Sketchbook)	• An animation/drawing and picture annotating tool to assist students' establishing connections between knowledge learned in the classroom and knowledge applied outside the classroom.	• **Engagement:** students record the changes of moist bread and toasted bread using Sketchbook.
(MapIt)	• A concept map tool that allows students to develop conceptual understanding through creating, sharing, and exploring concept maps.	• **Elaboration:** students draw concepts maps of the characteristics of fungi using MapIt.
(Blurb)	• A question setup tool which facilitates the teacher to set up specific questions to ask students to give short opinions or feedback on their inquiry activities or their understanding of knowledge.	• **Exploration:** students respond to the questions: how do the fungi grow? in Blurb.
(Recorder)	• A voice recorder tool for students to record the process of the experiment, fieldtrip and the observation of teacher demonstration, and students' reflection and conclusion are also recorded as a data for teachers' to review their progress and improvement in inquiry.	• **Exploration:** students record their questions when observing the moist and toasted bread using Recorder.
(Notepad)	• A data recording tool for students to record the results or process of experiments, fieldtrip, and observation of teacher demonstration.	• **Engagement:** students write their observations of the moist and toasted bread using Notepad.

implementation to assess the effectiveness of the curricular innovation when it is scaled up to a whole grade level. The yearly comparison of learning outcomes will be used for exploring students' progression in science learning, thereby demonstrating the value of M5ESC at scale.

4. Data collection and data analysis

In this project, the data collection for the curriculum implementation was conducted at each P3 class during the whole school year. The data sources included teachers and students performances in the classroom, teacher PD sessions and weekly group meetings, and students' work in and out of classroom. During classroom observation, two static cameras were set up in the front of and at the back of the classroom, and one mobile camera was used to capture the teacher–students interaction and target group activities. Audios were put at each group table for further capturing students' peer discussion. Using field notes, the sequence of key instructional events and main activities (e.g. lectures, hand-on activities, experiments, mobile learning activities and any activities regarding to the learning artefacts constructed by smartphones) were recorded. To capture teachers' thinking about their lesson enactment, video recorder was also set up at teacher PD sessions and their weekly group meetings to address the discussion of the lesson design, lesson enactment, lesson elaboration, as well as the challenges they encountered in the classroom. Surveys and interviews were conducted at different research stages for the research purpose.

In this study, data collection focused on three aspects according the research purpose: 1) classroom practices 2) teacher perspectives of M5ESC 3) students' learning performance. Data referring to classroom practices was used to examine the changes concerning:

- Teachers' pedagogical approach: a. their patterns of delivery lectures; b. the approach to organizing experiment; c. the ways of technology integration; d. the content of discussion activities; e. the purposes of teacher–student interaction.
- Lesson plan: the approaches to lesson plan design.
- Assessment methods.
- Linkages to the informal learning: activities conducted in the informal learning context.
- Classroom learning culture: students levels of involvement in the classroom activities and their levels of autonomy in the activities.
- Parents: the involvement levels of parents in the students' learning activities.

These dimensions were frequently discussed for exploring the classroom practices in other relevant studies and relative to the features of M5ESC and its PD efforts (Brand & Moore, 2011; Diaconu, Radigan, Suskavcevic, & Nichol, 2012; Donlence, 2003). Three researchers examined the classroom field notes, classroom observation sheets and rechecked the transcriptions of videos and audios through replying the videos and audios in the previous years (i.e. 2009, 2010, and 2012) and one researcher analyzed the field notes, classroom observation sheets and transcribed the videos and audios in 2013. Qualitative data analytical method was used to interpret and summarize the changes of the above mentioned dimensions. To attain the high inter-rater agreement, they discussed the transcriptions, rechecking coding and seeking for higher agreement (96%) on the data analysis.

To obtain further insight into teachers' ideas and thoughts behind the M5ESC implementation, the interview transcripts of science teachers from the same grade level (i.e. P3) were analyzed for examining their perspectives and experiences in implementing M5ESC. Five teachers, namely, Tom, Alice, Jemmy, Caroline and Jude, were interviewed at the end of academic year 2013 to probe possible changes. All the teachers had at least 3 year of science teaching experience with one year experience of M5ESC implementation, and they expressed

Table 2
Classroom practices on classification in P3 science.

Items	Pre-scaling phase		Scaling phase	
	Years 2009 (P3 traditional class)	Year 2010 (P4 experimental class)	Year 2012 (P3 M5ESC class)	Year 2013 (P3 M5ESC class)
Teaching approach	Traditional pedagogical orientation • Lecture: introduction-explanation • Experiments: "cookbook" pattern • Technology use: resource • Discussion activities: answers of worksheets and workbooks • Limited teacher–student interaction: answers, procedures	Somewhat constructivist pedagogical orientation • Lecture: questions-explanation-summary • Experiments: collaboration, sharing, and discussion • Technology use: resources, evaluation tool, reflection tool • Discussion activities: answers of worksheets and workbooks, learning artefacts • Teacher–students interaction: answers, procedures, knowledge	Constructivist pedagogical orientation • Lecture: questions, provide scaffolds, seek explanation, provide summary • Experiments: inquiry-based approach • Technology use: resources, evaluation tool, refection tool, comparison tool • Discussion activities: answers of worksheets and workbooks, learning artefacts, reflection, understandings, learning experience • Teacher–students interaction: procedures, knowledge, skills	Constructivist pedagogical orientation • Lecture: questions, provide scaffolds, seek explanation, provide summary • Experiments: inquiry-based approach • Technology use: resources, resources, evaluation tool, refection tool, comparison tool, sharing tool • Discussion activities: answers of worksheets and workbooks, learning artefacts, reflection, understandings, learning experience • Peer critique and activities: learning artefacts, understandings • Teacher–students interaction: procedures, knowledge, skills appropriate scaffoldings on knowledge building
Lesson plan	Teacher guide book • Teacher followed publisher's teacher's guide.	Revised teacher-guide book • Teacher and researcher revised publisher's teacher guide • Teacher and researchers co-designed school-based lesson plan	School-based lesson plan • Teachers implemented and enacted the school-based lesson plan in their classrooms • Teachers–researchers co-designed differentiated instruction content • Teachers-researchers co-design school-based worksheets	School-based lesson plan • Teachers elaborated and implemented the school-based lesson plan in their classrooms • Teachers implemented differentiated instruction in their own class • Teachers implemented the school-based worksheet
Assessment methods	Traditional assessment • Worksheet and workbook • Term-based tests	More formative assessments • Worksheets and workbook • MyDesk learning artefacts • Performance in group work • Term-based tests	Formative and summative assessments • Worksheets and workbook • MyDesk learning artefacts • Performance in experiments • Performance in group work •Term-based tests	Formative and summative assessments • School-based worksheets and workbooks • MyDesk learning artefacts • Performance in experiments • Performance in group work • Performance in activities beyond classroom • Term-based tests
Linkages to informal learning	Classroom learning	Informal learning • Home-based activities	Informal learning • Field trips: Zoo • Home-based activities	Informal learning • Field trips: Zoo • Home-based activities • Supermarket visiting
Classroom learning culture	Teacher directed classroom • Teacher directed the doing of worksheets and activities. • Teacher directed the experiments and hands-on activities • Teacher assessed students' work	Transforming to participatory • Teacher directed the doing of worksheets and activities • Teacher assigned discussion and sharing work to students in experiments and hands-on activities • Teachers asked students to do peer assessments of learning artefacts.	Participatory • Students participated in the experiments and hands-on activities • Students discussed their learning artefacts and shared the learning experience out of classroom • Students shared their ideas and knowledge in group work	Participatory • Students participated in the experiments and hands-on activities • Students discussed their learning artefacts and shared the learning experience out of classroom • Students shared their ideas and knowledge in group work and peer assessment of ideas and artefacts
Parent involvement	No involvement in outside activities	Some involvement in outside activities	Involvement of mobile activities outside of classroom	Involvement of mobile activities outside of classroom

strong willingness in transforming their classroom through innovative curriculum, and performed actively in the lesson discussions during the group meetings. The questions posed to them were: "If you think back, over the course of the year, what is the one thing that you feel is different about how you are teaching? How are you teaching that is different?" The discussions focused on the changes with regard to teaching strategies, content resources, activities, and assessment methods. One researcher transcribed the interview and analyzed the interview based on the transcriptions.

Moreover, student learning performance was examined based on their performance in and out of classroom. Students' attitudes toward learning activities and their involvement in these activities were interpreted as a part of analysis of the classroom practices. Their test achievements were compared and analyzed for revealing their conceptual changes impacted by M5ESC. In Singapore primary schools, all students would participate in doing the Semestral Assessment 1 (SA1) taken at the end of the first semester, and Semestral Assessment 2 (SA2) student taken at the end of the second semester. These two examinations were meant to provide summative assessment of students' achievement of understanding in science, and the results were used by the school as key indicators to evaluate students' progress over the year in Singapore. As official and standard tests conducted for the whole levels in the pilot school each year, the tests had been reviewed and validated by a group of experienced teachers in the school. Each question in SA1 had been examined as having consistent item difficulty as SA2. To test the reliability of the tests, a mock-up test with the similar difficulty levels of items and structures were conducted before each standard test. The mock-up test results were analyzed to revise the inappropriate items.

The total score of the tests was 100 with the SA1/SA2 tests comprising two components 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). Below are the exemplars of test items:

> **MCQ:** The flower of the morning glory plant blooms in the morning and closes when night falls. This shows that living things has the ability to _____________.
>
> (1) die (2) grow (3) reproduce (4) respond to changes
>
> **OEQ:** Teeth are very important to the digestive system. Give a reason why teeth are important.

To explore students' progression in conceptual understanding impacted by M5ESC enactment, especially concerning the learning gains of different ability students in M5ESC, we conducted a comparative analysis of P3 test scores during four consecutive years (i.e. 2010, 2011, 2012, and 2013) for evaluating the learning effectiveness on students' development in science concepts in more quantitative ways.[3] 2010 and 2011 are the pre-scaling phase in which the P3 classes had science lessons taught in their traditional way. 2012 and 2013 are the scaling phases in which the teachers in all the P3 classes taught using the mobilized curriculum. The yearly comparison of differences of SA1 and SA2 would provide us a more objective account of the different performance gains that different groups of students had achieved in different years. The comparison was expected to provide more evidence for supporting our research hypothesis that students would benefit more in reasoning and conceptual understanding with the use of M5ESC. Each year, these students at the P3 level were divided into eight classes (3A, 3B, 3C, 3D, 3E, 3F, 3G and 3H). The eight classes were further divided by teachers into three levels of ability, named as HA (High Achievement), MA (Mixed Achievement) and LA (Low Achievement) based on their prior achievements at the P1/P2 level. Quantitative data analytical methods were employed to compare the yearly difference of students' test performance. We firstly presented and described the overall performance gains and HA-MA-LA effects in 2012 and 2013 respectively. Then we compared the overall performance gains and HA-MA-LA effects of scaling phase with those of the pre-scaling phase, 2010 and 2011. Finally, we summarized the key findings from the quantitative analysis.

5. Findings

5.1. Comparison of classroom practices

M5ESC is about learning activities for students to probe, state, create and discuss their own understanding of science concepts using the MyDesk apps and its' assisting tools on the smartphones. It is also about students holding the smartphone as a learning hub from which they can initiate or continue learning activities anywhere even outside of the classroom. A substantial transformation is thus that students took more ownership of the learning with technology by recording or doing learning activities through the use of the smartphones. The teacher becomes a facilitator of learning in the classroom characterized by classroom discussion of the science ideas and students experiences. The students are more generative in their science ideas. This is evident in their attempts to fill in the OEQ with possible explanations albeit the answers may be incorrect.

In M5ESC classroom, teachers are encouraged to use more constructivist pedagogical approaches, that teachers value collaboration, learner autonomy, generativity, reflectivity and active engagement (Duffy & Jonassen, 1992). In detail, students' construction of knowledge is enabled by active participation in discourse, collaboration, and student-centered activities rather than transference from teacher talk. The teachers elicit and use students' existing ideas as a basis for helping them construct new, more reasoned, more accurate or more elaborate understandings (Holt-Reynolds, 2000), and use technology as cognitive tool to support student-centred curricula (Ertmer et al., 2012). To customize more appropriate M5ESC lessons based on school culture, teachers are suggested to be more open to redesign the lesson plan based on characters and levels of their classroom with the use of differentiated instructional approach (Tomlinson, 2001). They are proposed to integrate more formative assessment methods for evaluating students' performance in the inquiry process rather than emphasize the results of term-based tests. Gradually, teachers will have more understandings of connecting science learning in classroom and outside classroom, and could monitor and assess learning artefacts created outside classroom for supporting students' conceptual understanding

[3] 2010 and 2011 tests were selected because traditional science curriculum was implemented in all P3 classes. The 2009 was excluded because one of P3 classes implemented the M5ESC, which affected the test results in the whole level.

and skills development. Moreover, parents are also encouraged to involve more in the outside learning activities and assist in monitoring the work progress.

Table 2 shows a comparison of the classroom practices from the perspectives of the classroom teaching approach, design of lesson plans, use of assessment methods, linkages of classroom learning to informal learning, classroom learning culture, and parental support and attitudes. In Table 1, the first column shows the previous classroom practices before the M5ESC was enacted by all the classes (i.e. before it was scaled-up[4]). The column for 2010 presents the classroom practices of experimental class at P4 which is the first pilot class to experience M5ESC. The column for 2012 shows the classroom practices during the first year of scale-up to the grade level.[5] The column for 2013 is the second year of scale-up with M5ESC further refined based in the experiences and findings from the 2012 scale-up.

5.1.1. *Teaching approaches*

Positively, changes have been emerged after long-term intervention of M5ESC. In the initial stage of pre-scaling phase (the year of 2009), the teacher followed the traditional teaching approaches on the lectures, technology use, experiments and other hands-on activities. She mostly guided the classroom activities and monitor and assess students' work. As we found that teacher-guided pedagogical orientations were common in the lectures, the instruction of experiments and hands-on activities, and the ways of conducting other activities (e.g. checking and providing the fixed answers for students' completion of worksheets and workbooks; cookbook pattern of instructing experiments; few types of scaffolding for elaborating students' knowledge) (Ertmer, Gopalakrishnan, & Ross, 2001). Thus, few students-centered activities appeared in her classrooms, and students were rarely received opportunities of doing activities and discussing their experience within group members.

After one-year intervention, the teacher performed more skillfully on conducting experiments and discussion activities using some constructivist pedagogical approaches (the year of 2010). We found that she asked more questions instead of delivering information directly when she introduced a concept or science phenomena; she increased the use of smartphone in the classroom and extended the ways of technology integration on evaluation and reflection of learning artefacts; she would like to ask students to conduct several discussion work on assessing their learning artefacts done by MyDesk, and interacted more for providing knowledge of the procedures and knowledge on seeking for the solutions.

Supported by PD sessions and regular meetings, teachers developed more teaching strategies based on the constructivist pedagogical orientation in the scaling phases. When they did teacher talk, they would like to collect students' ideas and prior knowledge at first and posed questions based on students' responses. They conducted more inquiry-based experiments with attaching inquiry questions and emphasis reflection of the phenomena. When interacting with students, teachers valued more students' knowledge construction through peer discussion and peer assessment, and they interacted more frequently with students with purposes on detecting their understandings and guiding the knowledge construction (Orlando, 2013). Moreover, teachers conducted more discussion and sharing activities about students' learning artefacts done by MyDesk at outside the classroom. This stimulated students' self-directed learning using mobile phone beyond the classroom (Wong, 2013).

5.1.2. *Lesson plan*

The analysis of lesson plans is a suitable approach of gaining insight into teacher competence (Tillema, 2009). Instructional planning has been perceived as an important process in the professionalization of teachers (Ruys, Keer, & Aelterman, 2012). In our project, the development and elaboration of the M5ESC lesson plans is one of the scaling endeavors. The co-design process of lesson plans can help teachers to understand the underlying principles of the activity design and the proposed teaching strategies of the specific content, and to learn from the more experienced teachers. After implementing one-year of M5ESC, teachers' design methods of lesson plan were changed from copying teacher guide book directly to co-designing the school-based lesson plan, which indicated that the teacher involved more in the lesson plan design to adapt the M5ESC and respond more appropriately to the ideas that students raise during instruction (Sherin & Drake, 2009).

With the deeply practicing M5ESC, teachers processed strong willingness to elaborate their teaching strategies based on their teaching practice and students' needs. For example, M5ESC was first designed for a MA class. The lesson plan for two years of science curricula for P3 and P4 was amongst the outcomes of the first research phrase. During the scaling phase, the lesson plan was discussed and revised arising from discussions in teachers' regular meetings. One realization that emerged as teachers of one grade level started to teach the curriculum to different ability students was the need for differentiated instruction. The teacher faced challenges in managing learning in a diverse classroom using the same set of lesson plan and resources (Tomlinson, 2000). And on the other side, differentiated instruction focuses on teaching strategies that give diverse students multiple options for taking in and processing information, making sense of ideas, and expressing learning. The use of technology tools could provide students with different levels of interaction with software, conduct inquiry activities and create learning artefacts (Smith & Throne, 2007). Consequently, M5ESC were elaborated and differentiated to challenge HA and MA students accordingly to their abilities at the scaling phases. In the 2013 M5ESC lesson plan, HA, MA, and LA students were required to construct and synthesize knowledge with different levels of scaffolds. The HA, MA and LA used the same learning activities but required to produce different levels of same learning outcomes. Teacher efforts on the implementation of differentiated instruction could be detected in the classrooms at the later stage of scaling phase.

5.1.3. *Linkages to informal learning*

Creating seamless learning environment for students' inquiry through connecting formal learning with informal learning contexts is an important feature of the M5ESC. Teachers' efforts on designing, implementing and assessing students' learning activities beyond classroom were identified as the main indicators of their competency on the instructing M5ESC lessons. We found that with the improvement on the

[4] One experimental class in the grade level was involved in the research as P3 in 2009 and as P4 in 2010, but for the other classes, science was taught in the manner described in the first column.

[5] It was a year in transition as teething problems emerged during the teacher enactment of M5ESC, and the teachers and researchers deliberated and worked collaboratively to fine-tune M5ESC, and adopted or revised new strategies to better support the enactment. Hence the column for 2013 is different from 2012.

skills of designing mobile learning activities for informal contexts in the scaling phase (e.g. home, zoo, botany, etc), teachers designed more students-centered mobile activities to relate students' understanding with real life experience and to improve understanding through applying the knowledge in daily life, and with the result of teachers' increasing the use of mobile technology in classroom and out of classroom. For example, in the 2013 P3 zoo trip, more instructions and scaffoldings were provided for students to complete the tasks of classification of the animals and identifying the characteristics of the animals, with the use of mobile phone to collect their evidence and record their observations. More group discussions were found during the zoo trip. Consequently, with the increase of the efforts on informal leaning design and implementation, students in 2012 and 2013 participated more actively in the learning activities compared to the students in 2010 and 2011. Students became more interesting and engaged in the learning activities and would like to share their ideas and knowledge with their classmates.

5.1.4. Assessment methods

In the scaling phase, the term-based tests and students' worksheets were not the only assessment instrument, students' performance in doing activities and the artefacts done by MyDesk had been selected as another indicators for teachers' evaluating students' improvement and progression. For example, in the topic of "Exploring Materials", students were required to complete a series of tasks including constructing a concept map in MapIT for materials classification after they explored the experiments of materials and their properties, and writing their reflections on what they had learned in KWL, and connecting and applying their understanding in daily life through posting a pic of product and pointing out its materials and properties. It was found that more than 50% of the students posted their learning artefacts with different understanding levels. We illustrated three Sketchbook artefacts constructed by students (Fig. 2). And a considerable proportion of artefacts reflected that a number of students attained high understanding levels. The identification of the different levels of learning artefacts served for the teacher to monitor students' progress and provided in-time feedback for students to elaborate their understanding, as well as promote students to review and reflect on their learning process.

5.1.5. Classroom learning culture

Participatory learning culture advocates the engagement of students to share and distribute knowledge within learning communities in the ICT learning context (Reilly, 2009). In M5ESC, the emergence of the participatory culture in the classroom has been identified as another change in classroom practices with M5ESC. With constructivist pedagogical approaches deployed in the classroom in the scaling phases, students received more opportunities in articulating their understanding, sharing their prior knowledge, commenting on their learning artifacts and elaborating on their thinking during the group work in doing experiments, hands-on activities and mobile activities. We found that students' learning became more inter-dependent when they faced the complex tasks out of the classroom. This indicated that the changes of classroom culture influenced students' learning at outside as well. With the increase of students' autonomy learning in and out of the classroom, they became more confident in doing the activities when they were required to complete the tasks by themselves.

5.1.6. Parent involvement

There were also some shifts in the role of parents during the scaling phases. Their foci have been moved from an emphasis on students' test results and answers in worksheets to also look at students' performance in completing the tasks of mobile learning activities. They could assess students' MyDesk and review their KWL reflections, quality of concept maps and work done in the Sketchbook to glean more information on their children's learning process and thereby provide in-time feedback. When they received positive results, the parents became involved more and aware of what their children were learning, they were willingness to assist their children's outside work and interacted teachers with feedback and suggestion.

5.2. Teachers' perspectives of M5ESC

At the beginning of the M5ESC implementation, as Tom had low confidence in enacting the curriculum, he relied mostly on the textbook and teaching resources for preparing the lessons, and did not have a deep understanding of the principles of the M5ESC. After joining the group meetings and doing the lessons, he developed more confidence in implementing the curriculum. He noted the changes in students that resulted from the autonomy given to them in doing their hands-on activities and their participation in peer discussion and sharing of their learning experiences. He found that students become more engaged in the discussion and sharing work:

> "Now I have more confidence to conduct the activities from M5ESC. When I saw my students were actively discussing their work and sharing their ideas with their partner, I understood the value of student-centred activities. I attempt to conduct more activities based on

Fig. 2. Students' learning artefacts in MyDesk.

Table 3
Distribution of students.

Ability levels	2010	2011	2012	2013	Sum
HA	121	132	128	128	509
MA	142	111	119	114	486
LA	32	54	52	63	201
Sum	295	297	299	305	1196

> the co-designed lesson plans to develop students' skills in collaboration and communication. And I'm amazed that there are kids that will conduct experiments or doing activities at home even though they were the weaker lot and their parents were also quite supportive. Most students could post their work done out of classroom, and they shared their process with their classmates and peer assessment of each other's work, they enjoyed the learning process and seemed to be more engaged in the mobile learning activities compared to the paperwork activities. "

Previously, Alice felt that the lack of her ability of doing technology integration was the obstacle for implementing mobile learning activities in the class. But later, she was able to apply technology in more activities with different cognition levels into the class (Starkey, 2011). During these activities, she valued students' participation and contribution to their own inquiry activities. For example, in the lesson of "Exploring Materials", the students developed deeper understanding of the properties and value of the materials and objects in their daily lives after they engaged in a series of activities using Sketchbook in MyDesk: looking for the products → taking the pictures → describing the constituent materials → pointing out the values and properties of the materials.

> "But what I like about the phone is that the alternative platform allows children who may be reluctant to do the written work part … they at least have an alternative tool to get them to draw, to record, to crate and to generate their own work. The use of smartphone opens up my ideas on the technology use in more learning activities with different learning objectives. For example, I can teach students' skills on data collection using camera and audio recorders in the smartphone; and I can ask students to practicing their reflective thinking skills using the KWL app, and assist students to develop systematic thinking skills through using MapIT app. These did not happen in my previous classroom."

Jemmy shared that his students now spent more time on learning from books, and as they pursued understanding through interacting with teacher and their classmates, they become more open to peers' experiences for better understanding. These changes emerged after he implemented M5ESC for around one year. The same changes were found in their ways of seeking for answers that they would rather do peer discussion with their partners and not directly approach the teacher. Jemmy felt that he now paid more attention on how to scaffold students' peer discussion while knowing more about students' prior knowledge and providing appropriate scripts or prompts for them to find the solutions.

> "I guess I am using more inquiry-based teaching in class. I am more conscientious with using the inquiry-based teaching in class. I probe more – usually when my children do not give the answer, I will just tell them the answer, like 'hey this is it'. But now is like I probe a little more, I ask more questions and I get them to think more. Interestingly, students were not eager to get the answers from me but discussed with their partners until they reached the same answers."

Caroline felt the major change was her ways of assessment in science. Her previous focus was on students' answers in worksheets and workbooks; she emphasized more on students' SA1 and SA2 scores. She had gradually balanced her focus on the formative and summative assessments after intervention. She thought students' responses to KWL, learning artefacts constructed by Sketchbook and MapIT provided valuable information on what levels and how the students were learning. More importantly, assisted by mobile technology, she could access students' work anytime and anywhere. Students benefited from her in-time feedback and assessment, especially for the low ability students who may require more assistance from her.

> "Previously my science teaching is more like a paper kind of evaluation, even when we have science process skills (a worksheet), we have alternative assessments, having hands on that kind of thing …. We don't have time to see what the student is thinking. But right now with the smartphone, especially when I use applications like Sketchbook and MapIT, I am able to give more opportunities for children to explain their thinking, to express their thinking, although we do not have the time to evaluate their answers, but it gives me a very fast perspective of general understanding of the kid."

Jude thought previously she had been playing the same role in the front of classroom, namely, lecturing to the class; she acted more roles in the class now. She became more mobile and flexible for facilitating students' group work and providing scaffolds when students required for assistances. In most occasions, she performed as a collaborator for joining students' collaborative or sharing work, and meantime monitored students' progress and provided in-time feedback for their problems. She felt although she became more busy while implementing M5ESC but students benefited more from her scaffoldings.

> "The difference is in the way I conduct my lessons because now I used to ask questions where I want a certain kind of answer from the pupils but now I let them answer freely according to how they think they want to answer it and I'll adapt from there. By adapting from there, I mean I don't say that their answers are wrong and try to steer them towards my answer but instead I joined their discussion and get them to rethink about whether what they have answered is the correct way of answering. Then they themselves discussed with one another and guide them to correct each other on the misconceptions and so on"

Table 4
SA1/SA2 HA-MA-LA gains of year 2012.

	MCQ gains	OEQ gains	Total gains
All classes	0.49%	**27.04%**[a]	7.69%[a]
	$t = .406$	$t = 11.845$	$t = 6.584$
HA classes	−5.04%	**11.71%**[a]	5.04%
	$t = -5.987$	$t = 7.798$	$t = .535$
MA classes	0.91%	**29.55%**[a]	8.62%[a]
	$t = .595$	$t = 8.835$	$t = 6.047$
LA classes	13.16%[a]	**60.30%**[a]	**23.49%**[a]
	$t = 2.487$	$t = 7.071$	$t = 4.809$

[a] Statistically significant.

5.3. *Students' yearly progress in conceptual understanding*

For the year of 2010, 2011, 2012 and 2013, there were 1196 students in total; 295 students in 2010, 297 students in 2011, 299 students in 2012, and 305 Students in 2013. Table 3 shows the distribution of P3 students in HA-MA-LA.

Through data analysis of yearly SA1 and SA2 scores attained by these students, the impact of M5ESC on students' conceptual understanding was gradually increased year by year.

5.3.1. *Overall performance gains and HA-MA-LA effects of year 2012*

Year 2012 was the first year in which the whole P3 level implemented M5ESC. To compare the overall performance gains, a one-sample *t*-test (Table 4) was conducted (Some significant gains are highlighted in bold in the table). The result showed that the whole P3 cohort has made a significant increase of 7.69% from SA1 to SA2 in terms of total scores ($t = 6.584$, $p < .05$). It was prominent to note that such a progress is mainly attributed to their gains in 27.04% increase of OEQ scores ($t = 11.845$, $p < .05$) since they experienced a slight (not significant) decrease in MCQ scores. This indicated that in 2012, most students developed deeper understanding and reasoning skills through reasoning about the scientific phenomena and through the teacher providing the principles or relevant knowledge for clarifying the understanding of the students.

Table 4 also shows the performance gains from SA1 and SA2 on the MCQ, OEQ and total scores respectively in the HA, MA and LA groups of Year 2012. Specifically, comparing to other groups, the LA group achieved the highest MCQ gains at 13.16% ($t = 2.487$, $p < .05$), the highest OEQ gains at 60.30% ($t = 7.071$, $p < .05$) and the highest total gains at 23.49% ($t = 4.809$, $p < .05$). Additionally, the HA group achieved significant OEQ gains at 11.71% ($t = 7.798$, $p < .05$) and the MA group achieved significant OEQ gains at 29.55% ($t = 8.835$, $p < .05$).

In summary, from the SA1 to SA2 comparison of year 2012, we learnt that the whole 2012 cohort has achieved significant gains in total and OEQ scores. The improvement in OEQ scores was the major reason for the improvement of the total score in all levels. In particular, the MA and LA cohorts experienced more SA1/SA2 gains compared with the HA cohort, especially with respect to gains in OEQ scores.

5.3.2. *Overall performance gains and HA-MA-LA effects of year 2013*

Year 2013 was the second year for the whole P3 level to implement M5ESC. The one sample *t*-test showed that the whole eight classes have made a significant increase from SA1 to SA2 in terms of total scores ($t = 13.626$, $p < .05$). Such a progress was attributed to their learning gains in terms of both OEQ scores ($t = 16.514$, $p < .05$) and MCQ scores ($t = 5.978$, $p < .05$).

The P3 cohort of Year 2013, also consisting with HA, MA and LA classes, achieved gains for each ability group (Table 5). Our analysis showed that most of the HA-MA-LA classes have had a significant increase from SA1 to SA2 in terms of MCQ scores, OE scores and total scores, except that the LA classes has not achieved significant increase in the MCQ gains.

5.3.3. *Overall performance gains and HA-MA-LA effects in four consecutive years*

We seek to compare the SA1/SA2 performance gains of Year 2012 and 2013 (scaling phase) with the previous Year 2010 and 2011 (pre-scaling phase). As Fig. 3 shows, there was a prominent average improvement of 23.64% in OEQ scores in 2012/2013 compared to the average 8.11% improvement in 2010/2011. The average 8.89% improvement in total scores in the scaling phase is also higher than the average 5.05% improvement in the pre-scaling phase.

A yearly comparison of performance gains was also conducted to investigate the differences between the years, as shown in the following Fig. 4. It is noted that LA cohort of year 2012 achieved the most prominent 60.3% increase as OEQ gains. The overall OEQ gains of year 2012 (27%) is the highest amongst the years, followed by year 2013 (20.33%). The MA cohort of year 2012 also achieved the highest OEQ gains

Table 5
SA1/SA2 HA-MA-LA gains of year 2013.

	MCQ gains	OE gains	Total gains
All classes	6.91%[a]	20.33%[a]	10.07%[a]
	$t = 5.978$	$t = 18.514$	$t = 13.626$
HA classes	3.53%[a]	16.30%[a]	7.7%[a]
	$t = 3.24$	$t = 15.021$	$t = 10.1$
MA classes	10.98%[a]	23.07%[a]	13.86%[a]
	$t = 5.52$	$t = 12.527$	$t = 10.643$
LA classes	6.41%	23.55%[a]	8.03%[a]
	$t = 1.449$	$t = 4.587$	$t = 3.198$

[a] Statistically significant.

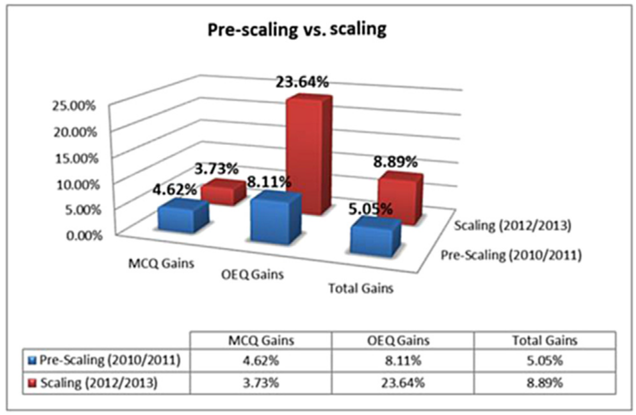

Fig. 3. Comparison of pre-scaling and scaling on performance gains.

(29.55%), followed by the MA cohort of Year 2013 (23.07%). The LA cohort of Year 2012 experienced the larger improvement in both MCQ scores (13.16%) and total scores (23.49%) than other years.

Comparing to year 2012, year 2013 had a more balanced result in MCQ gains (6.91%), OEQ gains (20.33%) and total gains (10.07%). The HA cohort of Year 2013 experienced higher gains in OEQ scores (16.3%) and total scores (7.7%) than previous years. The MA cohort of Year 2013 had the highest improvement in MCQ gains (10.98%) and total gains (13.86%) in the four years.

The comparison of performance gains from SA1 to SA2 over the four consecutive years provided an overall map of the effectiveness of implementation of M5ESC at the grade level. In summary, the students in P3 were responding well to OE questions, thus suggesting that the students had developed deeper understanding of the concepts. The whole cohorts of years 2012 and 2013 improved significantly on the OE questions than on the MCQ when compared with how they did on the OEQ questions in 2010 and 2011. It suggested that the elaborated M5ESC and teachers' adaptation of the curriculum in scaling phase contribute to students' progressions in science learning.

The learning experiences of M5ESC did generally significantly benefited the MA and LA groups. The HA group already had high scores on both the SA1 and SA2 tests and on both sections, MCQ and OEQ. With the elaboration of the M5ESC and the development of teacher competency on the M5ESC implementation, the SA1/SA2 gains in Year 2013 are more robust than Year 2012. All HA-MA-LA cohorts of year 2013 have generally achieved significant increases in both MCQ and OEQ scores. The HA cohort of Year 2013 was still capable of making prominent progress in both MCQ and OEQ. It is essential that the students did not do better on OEQ at the expense of MCQ.

6. Discussion

Addressing issues of research on curriculum innovation and its scaling, our study attempts the establishment of a research model of how to develop a curricular innovation for small-scale pilot study moving onto large-scale implementation. Our study also seeks how to measure the success of the innovation. Indeed, the innovation has been described as a multidimensional phenomenon and there are many obstacles

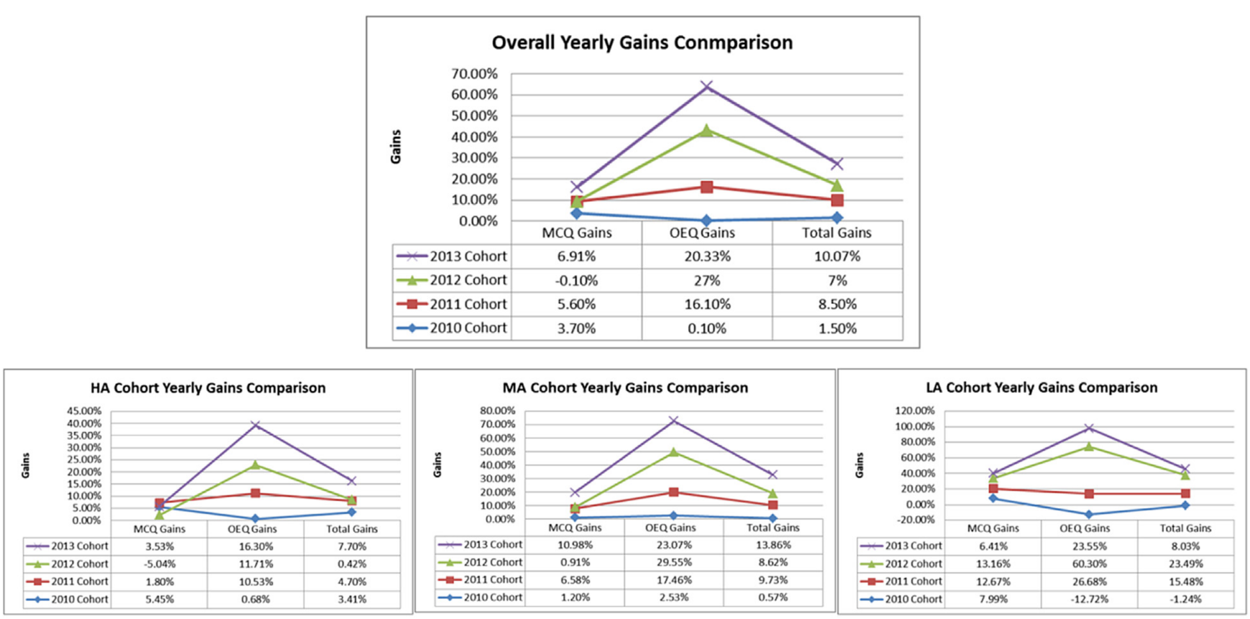

Fig. 4. Comparison by year of performance gains.

placed on the path from concept to reality under practical circumstances (Altrichter, 2005). Through five years of research intervention, we recognized that the success of the curriculum innovation in terms of changes in classroom practices and in students' learning performances on their science assessment is due in large part to the methodologies employed in the curriculum development and the strategies that supported teachers' enactments of the curriculum through a continuous consultative process of fine-tuning the curriculum and implementation, as well as the dual interaction among the factors of innovation at different stages. More importantly, we retrieve and relook at the practice of the curriculum from the initial stage to the implementation stage, which has been a challenge in educational research that forming an innovation that both analyzes the past and look to the future effectively (Keene, 2013).

In this study, we do not intend to provide the whole picture of our curricular innovation in this study, but we hope our research could help others divine the whole from a valuable part in the study. Our study focuses on addressing the two research questions concerned with how to design and scale up such an innovation and articulating the results of the innovation implementation. As we discussed in the Literature Review and Context, the design and scaling up of M5ESC followed the principles of scaling up evidence-based practices which developed from the emergence of the scaling up proposal based on the initial evidence collected from the experimental class, and the demonstration of the learning effectiveness of the scaling efforts to the elaboration of the curricular innovation. Finally, the experiences gained and results obtained were fed back into the loop to enable further scaling at more grade levels. Tracing the whole scaling development, we could ascertain that the stage-by stage scaling method based on evidence from empirical studies was effective as relevant studies discussed earlier (Fullan & Stiegelbauer, 1991; Walker, 2004).

To demonstrate the effectiveness of the curricular innovation at scale levels, we conducted an extensive and systematical investigation of the changes of classroom practices regarding to teachers' teaching approaches, lesson plan, assessment, linkages to the informal learning, classroom learning culture and parent involvement. Aligning with the changes of the classroom practices, students' performance in and out of classroom has been inevitably changed. Overall, the year to year comparison provides some validation that the scale-up of M5ESC is effective. Moving from employing a direct instruction, memorization-oriented pedagogy to an inquiry and question-asking pedagogy requires a major change in teachers' behaviors and beliefs. Teachers particularly need some time to adapt the inquiry-based curriculum supported by mobile technology and digest the relevant principles for integrating the technology in and out of the classroom. Thus, their beliefs, competencies and skills of M5ESC implementation and attitudes toward the M5ESC which were also frequently discussed in other studies have been the foci of the long-term innovation efforts (An & Reigeluth, 2012; Drent & Meelissen, 2008).

Based on classroom observations over the five years, we know that teachers had transformed their pedagogical approaches in more constructivist ways (Voogt, 2010), that they conducted more student-centered activities and emphasized students' autonomy in the experimental and hands-on activities. They extended the ways of using technology in both classroom and outside of classroom. They experienced changes in their own teaching as well as changes in students. Students performed more actively and engaged in the classroom activities and mobile learning activities. They developed more learning skills, such as inquiry learning skills, reflective thinking skills and reasoning skills with participating more inquiry-based activities and completing mobile learning tasks using different learning tools. The comparative analysis of four consecutive years' test scores demonstrates that the changes of classroom practices influenced their test achievements further. Not only a progression of improvement in students overall performance made in the test scores, but also their performance in responding to OEQ as suggested by the yearly comparison above. In particular, the LA classes benefited more. The experienced teachers expressed their positive thoughts on the changes of their classroom relative to the students' performance in group activities, the advantages of formative assessment of students work done at outside, the roles they acted and the ways of technology. Their findings and thoughts provided supplementary evidence for confirming our assertions. In summary, we established that M5ESC can transform classroom practices and raise student achievement in the context of the scale-up to all classes in a grade level and implementation of the curriculum.

7. Implications

Innovation is indeed a complex process and scaling innovation is even more. Drawing on our efforts on this five-year curricular innovation for educators and researchers, we conclude that the success of the innovation can be maximized if the long-term trajectory of implementation could follow the design-based research and emphasize the evidence-based efficacy intervention (Penuel & Fishman, 2012). Scaling an innovation which has been developed by design-based research requires a long time frame and deployment of a range of methodologies, including design-based research studies in classrooms and small-scale field tests to establish the feasibility of implementing interventions in multiple settings (Sloane, 2008).

Increasingly, experts call for better consideration of the educational system as a whole to inform the design of large-scale innovations and to better understanding of the complexity behind the implementation and sustainability of large-scale curriculum innovations (Fullan, 1991, p. 154; Geijsel, Sleegers, van den Berg, & Kelchtermans, 2001). Thus, we need to identify the barriers encountered by different stakeholders at different development stages. The major target is the teachers who practise the innovation. Teachers as the most important stakeholders in the scaling process of the curricular innovation are most often discussed and their teaching are the most essential components for educational progress (Bybee, 1993). We found one enabling factor is devoting many opportunities and time for teacher to have professional development and learning, as teacher change has been directly linked with planned professional development activities (Clarke & Hollingsworth, 2002). The PD can focus on pedagogical content knowledge, principles of technology integration, and constructivist ways of conducting activities. Thus, structured PD sessions consists of research sharing (i.e. pedagogy, principles and teaching strategies), lesson design, lesson elaboration and reflection aligns with the development and scaling up of the innovation by being responsive to the needs of teachers. The PD sessions become an important avenue for us to understand teachers' readiness, their pedagogical beliefs on the technology use, as well as the response of parents and challenges faced by the teachers. Second, the genuine support of teachers is necessary for any attempt at change (Hargreaves, 1993). In M5ESC, teachers as the main practitioners were voluntary in designing, practicing and elaborating the lessons. Followed by the effective PD model, the teacher-led PD sessions provide teachers with high autonomy in making decisions on lesson design or revisions (Taitelbaum, Mamlok-Naaman, Carmeli, & Hofstein, 2008). They performed very actively and collaboratively to work with researchers to scale the curriculum, we well as being open-minded in receiving the feedback and critically reflecting on the enacted lessons. The teachers' enthusiastic involvement in the scaling of innovation guarantees the accomplishment of the innovation.

The scaling phases are not the end of an innovation, but it is a continuing process for elaborating the innovation, promoting teacher growth, and pursuing the desired learning outcomes. Long term efforts should be devoted to training teachers, evaluating the performances and observing changes. Further, longitudinal studies on the tracing of the changes could have a leading contribution on the research of the scaling up of the innovation, and enlighten relevant studies on how to capture the turning points of the innovation development and how to illuminate the growing picture of the innovation as it unfolds and scales up. In summary, this narration of the ongoing research journey from innovation to practice and to scale can inspire other research initiatives that will address the multi-term, multi-pronged, multi-level and systemic aspects of school-based innovations, and that yet at the same time, advance theory, frameworks, design principles, resources and strategies for effective and sustainable mobile learning.

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