
Volume 55, issue 4, December 2010
ISSN 0360-1315
ELSEVIER
Computers & Education
An International Journal
Editors:
Rachelle S. Heller
Jean D.M. Underwood
Chin-Chung Tsai
MAKE AN IMPACT
Impact Factor
2.059
GET READ
Available online at www.sciencedirect.com
ScienceDirect

Computers & Education 55 (2010) 1504–1523

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

# Deconstructing and reconstructing: Transforming primary science learning via a mobilized curriculum

BaoHui Zhang [a,*], Chee-Kit Looi [a], Peter Seow [a], Gean Chia [a], Lung-Hsiang Wong [a], Wenli Chen [a], Hyo-Jeong So [a], Elliot Soloway [b], Cathie Norris [c]

[a] *Learning Sciences Laboratory, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore 637616, Singapore*
[b] *University of Michigan, Department of EECS, College of Engineering, 2260 Hayward, Room 3629, CSE Building University of Michigan, Ann Arbor, MI 48109, United States*
[c] *University of North Texas, Department of Learning Technologies, 3940N. Elm, G 150 Denton, Texas 76203-0530, United States*

ARTICLE INFO

*Article history:*
Received 28 March 2010
Received in revised form
16 June 2010
Accepted 18 June 2010

*Keywords:*
Science Education
Computer-mediated communication
Elementary education
Teaching/learning strategies
Mobile learning
Curriculum development

ABSTRACT

The history of science education reform has been fundamentally centered around science curriculum development and implementation. The advent of mobile technologies has necessitated a re-examination of how students could better learn science through these 21st century tools. Conventional teaching materials may not prepare students to learn the inquiry way and to become self-directed and social learners who could learn "everywhere and all the time (seamlessly)" using mobile technologies. This paper is based on our first year of work in our mobile learning research project in transforming primary three science lessons into a "mobilized" curriculum for a classroom context in which students routinely use mobile technologies. Using an exemplar fungi topic, we discuss our approach as well as experiences in deconstructing and reconstructing an existing curriculum through a co-design approach with teachers in a Singapore local school. In doing so, we make a contribution to the methodology for developing mobilized science curricula for in-class learning that also extends to out-of-class learning.



## 1. Introduction

The history of science education reform has fundamentally revolved around science curriculum development and implementation (Forbes & Davis, 2007). With the availability of increasingly affordable mobile learning devices and software applications that can be used for learning purposes, educators are becoming more excited about harnessing the affordances of mobile devices for supporting science learning. Mobile devices provide a platform for students to embark on project-based or inquiry-based science learning activities in and out of the classroom. By coupling the supporting technical infrastructures for mobile learning with good curriculum and pedagogical design, teachers can transform science teaching into personalised learning journeys for each student. Mobile devices are used as a hub to mediate all the learning inquiries and activities.

Mobile technology can also be used to support inquiry-based learning in novel ways. For example, every child can now have an Internet-connected computing device in the palm of their hand 24/7. To take advantage of this emerging pervasive technology, science educators need to develop curricula that specifically consider the affordances of these mobile technologies. However, although there have been studies designed for supporting student inquiry-based learning (Chen, Tan, Looi, Zhang, & Seow, 2008; Roschelle, Patton, & Tatar, 2007; Spikol, Milrad, Maldonado, & Pea, 2009; Squire & Klopfer, 2007; Vavolula, Sharples, Rudman, Meek, & Lonsdale, 2009) using mobile technologies, most of them were short-term explorations that may not have to be part of schools' existing science curriculum. This was the challenge we faced a year ago in order to make mobile technology an integral and essential element in the school curriculum. We had to transform the existing science curriculum into a "mobilized" curriculum because students in our experimental class took the same tests as other students in the same cohort. While we exploited the affordances of the mobile technology, we were expected to address learning objectives in the existing curriculum and to follow the existing curriculum schedule. This means that our redesigned science curriculum needs to be enactable in a typical classroom. We envision that the transformation of the existing science curriculum will have the following characteristics: first, the process will result in a gradual but fundamental change of the curriculum; second, the change will be sustainable; and third, the process may be challenging and costly in terms of time and effort. The priorities of our three-year mobile learning project are to:

* Corresponding author. Tel.: +65 97504938; fax: +65 65151992.
*E-mail address:* baohui.zhang@nie.edu.sg (B.H. Zhang).

0360-1315/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compedu.2010.06.016

(1) develop a methodology for designing an inquiry and mobile-device-based science curriculum, and (2) pilot-test the resulting curricular materials in classroom settings.

Norris and Soloway (2008) used the term "mobilized lesson" to describe a lesson that starts with an existing, perhaps paper-based lesson design, but then is transformed to make use of mobile technologies' affordances. The "mobilized curriculum" is a transformation from a more content-centered and teacher-centered infrastructure to a systematic student-centered infrastructure to foster personalised learning and self-directed learning (Looi, Wong, So, Seow, Toh, Chen, et al., 2009). Such a redesigning effort would require exploiting the affordances of mobile devices for effective learning. Affordances here are the characteristics of a physical object in supporting potential interaction (Gibson, 1977; Norman, 1988). We will elaborate the affordances of mobile technologies applicable to our context in a later section.

Indeed, a well-designed "mobilized curriculum" would enable the enactment of learning activities outside school. Providing students with 1:1 ownership and 24/7 access to mobile devices like smartphones would create the potential to use their devices to support informal learning. Our work in mobilizing science lessons is thus framed in the broader context of constructing "seamless learning" environments to bridge formal and informal learning (Chan, Roschelle, Hsi, Kinshuk, Sharples, Brown, et al. 2006; Looi et al., 2008). We want to go beyond classroom learning and explore the continuous, pervasive (therefore seamless), and longitudinal use of mobile technologies. Therefore, we aim to design a curriculum that facilitates and scaffolds student-centered learning activities that encompass formal and informal settings (i.e., in class and out-of-class lessons). In this paper, we will be focusing on the design of curriculum for in-class learning activities, which has the potential to be extended to out-of-class and self-directed learning in terms of the activity structure and use of software applications.

Naturally, as in any school-based intervention project, systemic considerations abound. Besides redesigning curricula, one must address associated issues such as professional development for teachers, assessment and funding for sustainability. However, in classroom-based research, staying focused is a necessity in order to create a substantive impact. For example, in addition to addressing the professional development needs of the teachers involved in this project, the researchers also involve the teachers to co-design the Science curriculum. Such concerted effort culminates with the transformation of the existing primary three science curriculum, as well as the knowledge and beliefs of the teachers. These serve as the cornerstones to sustain the MILE (Mobile Inquiry learning Experience) approach. The design guidelines and the process we used for mobilizing a primary three science curriculum will be described. The process model is meant to be adapted and generalized for redesigning curricula for different grade levels and subjects in the school. Some changes as results of the enacted "mobilized" curriculum will be reported, as well as implications and lessons learned to guide subsequent work. The description and discussion of the curriculum transformation process is mainly based on the exemplar science lessons on the topic of *fungi*.

## 2. Context and the existing P3 science curriculum

### 2.1. Context

We are collaborating with a school, North Coast Primary School (all names in the paper are pseudonyms), which had nine Primary three classes. The first three classes were considered as "high-ability" classes where the students scored higher at the end of 2nd year school examination than students in the rest of the six classes. The rest of the six classes were considered equivalent "mixed ability" classes because students with different levels of achievement were evenly distributed to each of the classes (Table 1). One of the average ability class, class 305, became our experimental class. There were 39 students in the class comprising 24 boys and 15 girls. We chose the class because its form teacher, Grace, was recommended to be our collaborating teacher. She coordinated the operation of the class' activities in school and taught English, Math, and Science (EMS) to the class. She had been teaching in the school for more than three years. The school chose her to teach the experimental class because she felt comfortable in using technology. She was quite receptive to new ideas. She wanted to collaborate with the researchers to enrich her knowledge and skills in using mobile learning to improve student learning.

Prior to the introduction of mobile devices in the early part of 2009, we went into the class to observe the classroom practices and the students' behaviors to understand the class environment and culture. We collected student worksheets, assignments, and teacher resources. Based on the classroom observations and analysis of student artifacts, formative feedback was given to the class teacher to improve the classroom management. After six weeks of initial observation, we embarked on our plan to mobilize the P3 Science curriculum. At the beginning of the intervention, the students in the experimental class had a short session of device training lasting for 2 h. The science teachers also received some training in use of the mobile applications running on the device. To understand more about the existing teaching and learning culture of the class that we observed, we studied the existing science curriculum materials in use which are presented in the following sections.

**Table 1**
Description of experimental and control classes.

| | Experimental class | Control classes | Remarks |
|---|---|---|---|
| Teacher experiences | The teacher had about 3 years' teaching experience | Most of the teachers had taught longer than three years | Teachers other than Grace had equivalent or more teaching experiences than her |
| Student demographics | Average (mixed ability) class | Average (mixed ability) classes | The classes are considered equivalent |
| Teaching and learning routines | Mobilized science curriculum in all science classes | Regular teaching that is more teacher-centered | Students in control classes did not use handphone computers 24/7 |

### 2.2. Curricular materials to be re-designed for mobile technologies

In the Primary grade 3 and 4 Science Syllabus (Ministry of Education, MOE, 2008); there are five themes to be covered: Diversity, Cycles, Systems, Energy, and Interaction. The MOE Science syllabus states that:

> This syllabus is based on the Science Curriculum Framework and emphasizes the need for a balance between the acquisition of science knowledge, process and attitudes…Central to the curriculum framework is the inculcation of the spirit of scientific inquiry. The conduct of inquiry is founded on three integral domains of (a) Knowledge, Understanding and Application, (b) Skills and Processes and (c) Ethics

and Attitudes. These domains are essential to the practice of science. The curriculum design seeks to enable students to view the pursuit of science as meaningful and useful. Inquiry is thus grounded in knowledge, issues and questions that relate to the roles played by science in daily life, society and the environment (MOE, 2008, pp. 4–5)

All teachers have access to the information found in the syllabus. In addition, the MOE's Curriculum Planning and Development Division (CPDD) published a guide to complement the syllabus. The aim is to provide useful information and guidance for teachers on how to plan and deliver engaging and effective Science lessons.

Apart from the resources produced by the MOE, schools have access to MOE-approved materials that are produced by publishers. The materials from the publishers are seen as further interpretation of the MOE Syllabus. These publishers' materials include textbooks, workbooks, notes and enrichment materials. A publisher may also produce a Teacher's Guide that serves to scaffold and equip the teachers with inquiry-based skills. Schools have the autonomy to choose what curriculum materials they want to adopt for their students.

Included in the publisher's guide, are information about the content of the textbooks and workbooks that the students are using. In addition, Schemes of Work (SOWs), sample lesson plans and suggested pedagogical approaches with ideas about the use of technological resources are also embedded for teachers' consideration. SOWs provide an overview of how teachers can possibly sequence the topics. A school can adopt or adapt from this scheme to align the teaching pace with the activities of the school calendar.

Table 2 shows an example of the SOW for the topic *Fungi* that the students have to learn in Primary 3 in a textbook.

**Table 2**
An example of the scheme of work on the topic of fungi.

| Chapter title and sub– heading | Specific learning objectives in the book | Textbook and Workbook Sections |
|---|---|---|
| What are the characteristics of fungi?<br>Some characteristics of fungi:<br>1) What do different types of fungi look like?<br>2) How do fungi obtain food?<br>3) How do fungi reproduce? | In this chapter, pupils will learn and be able to:<br>1) State that fungi come in various sizes<br>2) List some examples of fungi of various sizes<br>3) State that micro-organisms are living things that can only be seen using a microscope<br>4) State that living things are also called organisms<br>5) State that some fungi are micro-organisms<br>6) Recognise that fungi are living things, which need air, water, and food to stay alive<br>7) Differentiate between fungi and plants<br>8) State how fungi reproduce<br>9) Describe how some fungi are useful and how some fungi are harmful | Textbook sections 1.1<br>Activity Book -Activities 1.1, 1.2 |

These current curricular materials for P3 or for science in general do not lend themselves to supporting inquiry-based learning using mobile technologies; mobile technologies were not readily available while the materials were being developed. We aim to transform the curriculum by deconstructing its components (e.g. learning objectives and their relationships, concepts, and learning activities) and reconstructing them according to a Mobile Inquiry Learning Experience, which is more student-centered and takes advantages of the affordances of mobile technology. We adopted a co-design process because teachers and researchers possess different sets of expertise and thus can create interesting synergy of ideas. It is only through collaboration that the innovative pedagogy can be realistic and be adopted by practitioners. For example, researchers may be more aware about the innovative pedagogies and potentials of mobile technologies. However, they lack the experiences of the day-to-day operation of the school and the profiles of students. On the other hand, teachers have in-depth knowledge in these areas but need to understand why and how they can possibly use mobile technology to facilitate student-centered learning. Through regularly held dialogues, the two parties seek to understand each others' perspectives so as to produce contextualized curriculum materials. The notion of transformation also means that we have to create a new curriculum which is a transformation of the existing curriculum and which fits into the current school schedule. The transformation has proved to be very challenging. Because the work lies in the crux of the technology integration reform effort, we would like to address it in this paper.

## 3. Design guidelines for mobilizing the curriculum

Since we have identified curriculum development as the first major task for our mobile learning project, we combined teacher professional development and curriculum development into a teacher-research co-design approach (Penuel, Roschelle, & Shechtman, 2007). The school identified a few science teachers including the form teacher Grace to participate in a curriculum task force with the researchers to work on the design of mobilized lessons. The mobile device that is used in this research is HTC Tytn II Windows Mobile phone that comes with photo-taking function, stylus pen, keyboard, 3G-enabled Internet surfing data plan and educational applications (e.g. GoKnow applications such as KWL-table for organizing what the user wants to know, wonder and has learned, Picomap for concept mapping, and Sketchy for creating animations). Our selection of the smartphone was based on the following criteria: First, it should be light enough so that students were willing to carry the device. We had considered UMPC and Laptop. During one field trip to Chinatown, some students used UMPC, which was smaller and lighter than a laptop, students still complained that the UMPC was too heavy. Second, we considered the compatibility the educational software we had. We chose a device that ran the GoKnow™ mobile applications – these applications were specifically developed for learning. And lastly, we predicted that using smartphone also as a learning device could be a trend because of the easy access to the wireless network and computing power vs. price.

In order to leverage on the mobile technology to create a holistic learning environment, we need to extract the overarching goal of the theme to connect and integrate the specific learning objectives. Understanding the overarching goal is important as it helps researchers and teachers in the co-design process to identify, structure, sequence, and implement the mobile technology-mediated activities. We designed our mobilized curriculum to be student-centered, inquiry-based, and collaborative in nature (Zhang, Wong, Seow, Chen, & Looi, 2009). In this transformation, we have applied the following design guidelines with consideration of foregrounding an inquiry science approach and the affordances of the mobile technologies. We were also cognizant of the need to have frequent and regular dialogues with teachers in the teacher-researcher task force to influence or change their knowledge, beliefs, and classroom pedagogies so that they would be able to enact and facilitate the mobilized curriculum in the classroom to achieve the desired outcomes.

### *3.1. Exploiting the affordances of mobile technologies*

Understanding educational affordances is important for adopting appropriate technologies to support learning (Churchill & Churchill, 2008). As a start, we designed scaffolding activities for formal learning to facilitate effective inquiry-based learning (de Jong, 2006). In pursuant of such efforts, students may internalise the inquiry-based learning principles. A corollary of such assertion is that the "mobilized" curriculum could serve as a scaffold to develop students' inquiry knowledge and skills. They could then exercise self-empowerment to direct their own learning even without the teachers' presence. For example, the mobile technologies could incorporate different learning modalities and make students' thinking process visible. These technological scaffolds facilitated sharing and critiquing. Students shared their work and refined their understanding through mobile-device-mediated collaborative learning (Rogers & Price, 2008). While we see great potential for mobile technologies to facilitate inquiry and student-centered learning, the existing science curriculum did not harness the affordances of mobile technologies. This is the major reason why we have proposed to redesign the curriculum.

The school has been using Windows Mobile devices such as Pocket PCs for several years for mobile learning activities. As such, there was a critical mass of technologically savvy teachers who were familiar with the use of the Windows-based mobile devices. The features required in the mobile phone would be based on the intended use for in class and out-of-class learning purposes. The school considered the following features for deciding the smartphone: 1) connectivity; 2) ease of use; 3) camera function; 4) geographic positioning system; and 5) technical support. The mobile device chosen was HTC TyTn II. The Microsoft Windows Mobile 6 operating system in the HTC Smartphone came with a calculator, a calendar, mobile web Internet access, MS Windows Mobile Word™, Excel™, and PowerPoint™, which provided the affordances of basic math computation, self-monitoring mechanism, digital production, data collection, data storage and analysis, and presentation.

We selected the GoKnow™ MLE (**M**obile **L**earning **E**nvironment) that runs on Microsoft Windows Mobile operating system because it supports collaborative inquiry. The Goknow MLE enables teachers to create differentiated lessons easily via its online learning management system, GoManage. Students can also easily personalize their learning experiences (Looi, et al., 2009). MLE supports teachers in creating complete, coordinated, curriculum-based lessons based on the principle of multimodal representations (e.g. text, graphical, spreadsheet, animations, and the like). It is an environment in which students engage in the specific learning activities to create various artefacts. It includes software tools such as:

- *KWL* (what do I already *K*now? what do I *W*ant to know? What have I *L*earned?) to allow students to learn through a goal-oriented process,
- *Stop Watch* that supports timing of events,
- *Sketchy*™ as an animation/drawing tool, and
- *Picomap*™ that allows students to create, share, and explore concept maps.

A teacher can customise student learning by creating assignments or tasks that are suitable for the interests and cognitive levels of individuals and/or sub-groups. With the tailored learning tasks, students have more opportunities and learning pathways by using different tools on the smartphones for their learning purposes. To illustrate, while students are doing their science experiments, they are entering text notes, voice notes and snapping pictures. Inasmuch as the computers are truly mobile, they can be woven into the fabric of both online and offline learning activities – an essential, integral component in the teaching and learning process.

We certainly also made use of other features of the hardware and software on the smartphone. Table 3 is a brief summary of the affordances of the mobile learning technology environment. It is a combination of the functionalities and pedagogical underpinnings (Churchill & Churchill, 2008; Patten, Sa'nchez, & Tangney, 2006) of the hardware and software tools on the smartphone.

**Table 3**
Affordances of mobile technology.

| Affordances | Learning opportunities enabled | Exemplar applications | Pedagogical underpinning |
|---|---|---|---|
| 1. Personal learning tool | It is a learning hub so that students can learn everywhere and all the time. The mobile phone computer integrates all personal learning resources at one place. | Mobile office suites: Word, Excel, PowerPoint; GoKnow Learning Management system and software suite (e.g. KWL for goal setting and reflection). | Ownership of constructed knowledge; motivating and engaging; self-directed learning. |
| 2. Contextualized learning tool | Mobility of the cell phone computer allows students learn in the context, such as science labs, field trips, and real time in classroom. | Photo taking, audio and video recordings not only allow data collection but also record context information where data is collected. | Meaning making; opportunities for generalization and making abstraction. |
| 3. Collaboration tool | Connecting students' mobile devices for communicating and exchanging ideas and artifacts. | Internet access, Wi-Fi, wiki, Bluetooth, phone call for information and data sharing. | Collaborative learning. |
| 4. Data Capture tool | Data collection as part of student inquiry process. | Photo taking, audio and video recording, sensors, probes. | Supporting inquiry, e.g. data collection and investigation. |
| 5. Visual articulation or translation tool | Students create multiple linked and multimodal representations to aid their thinking and learning. Newly available tools allow students to construct and manipulate data and artifacts. | GoKnow software suite PicoMap and Sketchy for artifact production; MS mobile Excel for data analysis. | Making thinking visible, manipulating multiple representations; higher-order thinking. |

For Table 3, the smartphone computer is a *Personal learning tool* because a student can own it for 24/7 for about two years. They were responsible for the basic maintenance of the phone, such as charging the battery. More importantly, they had ownership to the intellectual output they produce using the phone. Each phone has a special number and a label with the owner's name. It was, thus, not surprising that we found almost every student decorated their phone with special wall papers, stickers, and the like to make the phone unique to him/her. It was also evident that this personal learning tool motivated and engaged students over the course of their science learning. *Contextualized learning* is another desirable feature as students are able to engage in "authentic" scientific practices using tools and processes that are similar to that of scientists (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991), but immersed in contexts that are more familiar to them. However, this is not easily achievable unless students have mobile devices like the smartphone to capture data during field trips.

### 3.2. Use the smartphone as a learning hub to integrate formal and informal learning activities

Each student created and maintained a broad range of documents (artifacts) associated with each curriculum unit, e.g. concept maps, text documents, photos, and videos. All of the student's work was stored on the smartphone, which was, in turn, backed up onto the GoManage server using the cellular network for Internet connectivity. In order to realize the idea of "learning everywhere at all time", students need one or more digital devices that are mobile so that they can access learning platforms and resources everywhere and all the time. We have used hardware and software tools provided on the phone, and Goknow mobile applications to be the starting point for students to launch and continue their learning activities seamlessly, thus extending their classroom learning activities beyond school settings (Looi, et al. 2009). It is no longer assumed that student learning has to start from a teacher. Our strategy to prepare students starts from our formal learning design, but we hope that a mobile hub can integrate multiple learning experiences across *Process, Location and Setting, Purposes*, and *Content* (Malcolm, Hodkinson, & Colley, 2003).

We propose the learning approach to be project-based in order to sustain student investigation and collaboration (Blumenfeld et al., 1991) across formal and informal settings. Eventually, we hope that student-centered learning that is mediated by the smartphone can reduce the gulf in learning between formal and informal settings (Scanlon, Jones, & Waycott, 2005). In doing so, students can foster their routine use of the learning hub to manage their own learning.

### 3.3. Design student-centered inquiry-based learning activities

Researchers from studies like Programme for International Student Assessment (PISA) showed that students may not be adequately prepared for the world in which they will live and work (OECD, 2003). Inquiry learning can be a recommended approach to prepare and equip students with the required knowledge and skills. During inquiry-based learning, students might engage in the process of exploring the natural or material world; they need to ask their own questions, make discoveries, and test their hypothesis when trying to understand the world around them. Therefore, students are put in the centre of such learning, and they need to take initiative in their own learning. Inquiry learning bears similarities to scientific inquiry processes with the following constitutive cognitive processes: identification of variables and relations; hypothesis generation; experimentation; reaching conclusions; evaluation; and monitoring the process of knowledge development. However, past research indicated that students have difficulties in using those process skills (de Jong, 2006). Therefore, we proposed to harness the power of mobile technologies to address the challenges. Our proposed conception on seamless learning is aligned with the Singapore government's proposal to encourage inquiry-based learning that has been specified in its science syllabi including the primary science syllabus (MOE, 2008).

### 3.4. Making use of community support and resources

When students equipped with mobile technologies go mobile, they can tap on the world around them as the context for learning. There are community resources that are suitable for educational purposes, such as museums, science centers, cultural heritage sites, and public service providers (e.g. public transportation systems). They might have their own materials for visitors which are good starting points for students to learn in relatively informal settings. We hope to collaborate with them in developing mobile lessons that connect school curriculum to those resources. There are some digital resources, especially some resources that are hand-picked by educators (e.g. an Artemis digital library designed specifically for young children (Wallace, Kupperman, Krajcik, & Soloway, 2000) The benefits for making use of community resources is that learning becomes contextualized, authentic, and situated (Kurti, Spikol, & Milrad, 2008). The school we are working with has designed some mobile lessons when they organised trips to supermarkets, cultural heritage centers, Singapore Science Centre, and natural parks. Designing for holistic and authentic learning using community support and resources should make science learning more meaningful because these are the environments that students are familiar with.

### 3.5. Facilitate collaborative knowledge building

When students have opportunities to share their ideas and artifacts in the public space, they are able to engage in knowledge-building discussion in which students collectively revise each others' ideas to deepen their understanding (Vahey, Tatar, & Roschelle, 2007). The Partnership for 21st Century Skills (2003) argues that helping students to learn the core subjects is not enough, but rather that students need to learn how to appropriately use digital technology and communication tools to access, manage, integrate, and evaluate information, construct new knowledge, and communicate with others. The implication for such a notion is that students need to learn how to communicate with each other and to jointly co-construct knowledge. This kind of social knowledge building has been possible when students have mobile applications to create multiple representations with multimodalities and communicate via wireless networks (Rogers & Price, 2008).

### 3.6. Support teachers to be good curriculum developers and facilitators

Moving teachers away from didactic teaching is always a big challenge especially for teachers with limited teaching experiences. We introduced the idea of developing "Educative teaching materials" for this purpose (Davis & Krajcik, 2005). Being "educative" means having a function of teaching. We adopted four of the nine heuristics proposed by Davis and Krajcik (2005). The first heuristic is to support teachers in anticipating, understanding, and dealing with students' misconceptions about science. This was realized by sharing experiences and resources among members of our task force. A description of a learning scenario with possible student learning difficulties and strategies was generated and shared in the form of a word document, a concept map, or other digital materials. The second heuristic is to support teachers to learn and appreciate the affordances of mobile technologies. This was done by workshops with concrete examples on how to use the smartphone features and software applications. Third, we support teachers to enhance their subject matter knowledge. This was done by supplying extra readings about the subject topics in a broader context and exchanging ideas during the task force meetings. The last heuristic adopted is to support teachers to learn pedagogical content knowledge (PCK). This would allow inexperienced teachers to quickly identify students' common misconceptions and learning difficulties and to design appropriate pedagogical strategies. The teacher–researcher curriculum task force exchanged ideas on PCK quite intensively; there was also some information about student learning difficulties in the teachers' guidebook.

### 3.7. *Assess student learning formatively*

Students need time to reflect their learning journey and receive feedback on their learning in a timely manner over the course of learning in order to adjust their learning trajectories and deepen their understanding. The integration of formative assessment into any phase of inquiry, everywhere in the classroom or in the field has been made possible by the portability of the mobile devices. We mentioned the affordances of mobile technology and the intention to construct a collaborative learning environment around the use of the technology affordances. Through the co-construction of knowledge mediated by mobile technologies, students can receive feedback from peers, teachers, and experts by communicating, searching, and exchanging their artifacts and ideas. The GoManage server allows students to upload and update their work every time when they synchronize their smartphone with the server. Teachers and researchers actually went through student submissions to provide formative feedback. While our project's current priority was mobile curriculum development, formative assessment design is an on-going process and we were also exploring possibilities of software development for formative assessment (Penuel & Yarnall, 2005).

## 4. An introduction of the mobilized fungi curriculum

Before we describe the process of "mobilizing" the *fungi* curriculum, we provide an overview of the "mobilized" curriculum to set up the context before introducing the steps we undertook for the redesigning process.

Curriculum mobilization entails a holistic view of how learning activities can be organised via technology so that student learning is situated in authentic contexts. The MLE provides the infrastructure to develop a project with driving questions and learning objects. A project is a container of related and inter-dependent learning tasks. Each task is an instantiation of how mobile computing can be an enabler for personalised learning: (a) allowing multiple entry points and learning pathways, (b) supporting multi-modality, (c) enabling student improvisation in- situ, and (d) supporting the sharing and creation of student artifacts on the move (Looi et al, 2009). Students can pursue their inquiry in a personalised way, without having to do the tasks in a linear sequential order.

A good curriculum design will harness these affordances to transform science curriculum into a mobilized one that makes science learning motivating, engaging and holistic. The strategy we have adopted to achieve such learning goals was to spell out the differential learning behaviors that might lead to the desired outcomes, as compared to the conventional curriculum. Table 4 shows a comparison of conventional lessons and mobilized lessons on the topic of *fungi*. We compare student learning not only in the classroom but also out of the classroom to indicate the changed perspective on conventional curriculum design. This reflects our intention to encourage the use of mobile technologies everywhere and anytime.

These principles are exemplified in the example below. As part of the mobilized curriculum, students need to download the files teachers prepared for them by synchronizing their smartphones with the GoManage server. Fig. 1 is an excerpt of the learning objectives that

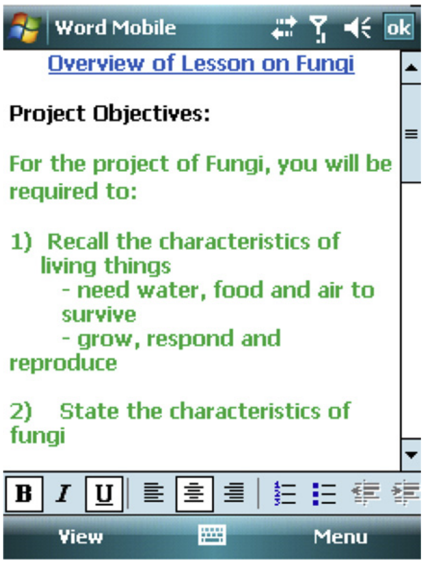


**Fig. 1.** Fungi learning objectives.

**Table 4**
Comparison of traditional and mobilized P3 science curricula.

| | Conventional learning activities | Mobile inquiry learning experience (MILE) | | |
|---|---|---|---|---|
| | | MILE activities designed | Rationale for choice of learning activities | Technology affordances |
| Formal classroom activities | Students used the activity workbook and textbook to construct their concept of fungi as living things by answering a series of worksheet questions (but have no opportunities to ask their own questions). For example, they were asked to draw and label a picture of a mushroom and to show the cap, gills, stalk, and spores. | Students filled in KWL to indicate what they knew, what they wanted to know, what they had learnt; they read PowerPoint slides about fungi and looked at photos of fungi; they watched videos on their mobile devices to observe how fungi grow and die; they created a table in Mobile Word listing why they thought fungi were living things according to the characteristics they had observed; they included fungi in their concept maps of living things; they discuss in class what they observed and made further connections to their understanding about characteristics and classification of living things by reviewing related files on their phone. | Students learnt science phenomena in real context for meaning making; students made their thinking visible and allowed teachers and others to share and give feedback to their created artifacts; higher-order thinking skills (e.g. analyzing, synthesizing, and evaluating) | Personal learning tool; contextualized learning tool; data capture tool<br>Cognitive tool; collaboration tool |
| Informal outside classroom activities | (According to the form teacher and another young teacher) None | Students took photos of fungi outside the classroom as an activity. They had access to MLE materials outside classrooms. The students actively planned their learning activities. They watched videos, create KWL charts and concept maps, and learnt from one another. They were engaged in self-directed learning and collaborative learning using their mobile devices. | Personal learning hub; students learnt science in real context for meaning making; they made their thinking visible and shared and gave feedback to each others' artifacts; higher-order thinking; and they could connect what they have learnt to real life experience | Same as above |
| Student's roles in the activities | Students completed the activity worksheets and read from the textbooks | Students compared the characteristics of fungi and living things by creating a table inside MS Mobile Word. Students did KWL to track their learning progress about fungi. Students created a concept map of their understanding of fungi. Students could engage in these MLE activities everywhere all the time | Learning was student-centered. | Actively engaged in his/her own learning; self-paced |
| Teacher's roles in the activities | The teacher followed the SoW and textbook closely in her teaching. She tried to complete the lessons and had the students complete the worksheets as required. | The teacher facilitated student learning by designing student-centered activities with task instructions, data tables, and digital artefact production and collaboration tools. | The teacher was the facilitator and regulator | Facilitating and regulating student learning |

students will see. These objectives are aligned with the requirements of the national syllabus. A complete guide on the lesson procedure is reproduced in Appendix. Table 1 shows an overview of the learning objectives of the existing fungi topic. The mobilized curriculum is designed with the listed objectives in mind. We anticipate that the diverse action verbs in the project objectives could lead to the development of both process skills and higher-order thinking skills. For example, children use KWL application to record what they wanted to know, how they came to know, and what was learned as an iterative process to plan and monitor their own learning. Students needed to demonstrate planning, analytical, reasoning and evaluating skills, as well as to develop metacognitive skills to manage their own learning journeys.

There were also some additional objectives the teacher and researchers planned for. However, these were not listed in the above MS word file in order to be more focused on the most basic objectives, such as: 1) State that fungi come in various sizes and list some examples; 2) Differentiate between fungi and plants; and 3) State how fungi reproduce.

Table 4 shows a summary of our consideration of the mobilized P3 science curriculum. We used the *Fungi* topic as an example because the scope of the topic is relatively manageable. It took about 8 periods to cover the topic. Moreover, this topic was taught in the middle of the year, thus teachers and students would already have had some experience in using the mobile devices when starting on this topic. In Table 4 we compare "Conventional learning activities", and the "Mobile Inquiry Learning Experience (MILE)" that we designed for the students. We described the "MILE activities" and added "Rationale for choice of Learning Activities", and "Mobile Technology affordances" that we leveraged to take advantage of mobile technologies. The comparison looks at the following four aspects: "Formal classroom activities", "Informal outside classroom activities", "Teacher's Roles" and "Student's Roles".

The teacher worked with the researchers to study the national syllabus, textbook, related materials, and the affordances of mobile technologies to define the learning objectives. Our strategy was to provide certain "structure" to allow students to acquire self-directed learning skills and to foster habits of minds so that they may transfer these skills to informal settings without intervention. For example, the frequent use of KWL is a form of enculturation where students learn to internalise skills such as asking good questions, designing investigations, collecting data, analyzing data, and making conclusions. Students may replicate such self-directed and inquiry-based processes when working on their personal projects. Although we are promoting student-centered learning, the role of a teacher is not eschewed. In fact, teachers need to help students learn the art of validating their solutions on-the-fly. A teacher who is not aware of what technology can offer may not be able to prepare students to learn effectively by connecting formal and informal learning.

## 5. Process of transforming the curriculum

In this section, we describe the emergent process in which we redesigned the P3 science curriculum to adopt an inquiry science approach as well as to harness the affordances of mobile technologies. For a given theme, we analyzed the essential learning points, identified the teaching focus, observed current classroom teaching practices, ascertained students' learning needs, and examined current lesson designs from SOWs. Through dialogues with teachers, we brainstormed the bigger ideas in the theme and created learning scenarios, focusing on opportunities for content creation or activity participation. These activities were aligned with the demands of self-directed learning and out-of-class learning. We also continuously provide feedback to the participating teacher to help her improve her teaching practices, In addition, we also collect feedback from students and teachers to further improve the design of the lesson.

We have adopted the metaphor of *deconstructing* and *reconstructing* to describe our curriculum redesign process (Looi, et al., 2009). Informed by the data collected from the practices above, we developed a model of our curriculum design cycle (Fig. 2). We will explain the use of the cycle with examples of the mobilized curriculum we have designed. It is noted that this mini cycle is embedded in larger cycles when we were considering the overall design for the diversity theme. This means such a cycle is an iterative process that is interwoven across our whole design journey, and now we zoom into one of the basic units to elaborate the rationale and process. The cycle was crystallized after several mini design cycles. We use dashed line to indicate that in reality the order of the steps might change or some steps could be combined when curriculum developers are more experienced with the design process. The solid line arrows indicate that the formative evaluation of the design are on-going because of the nature of research design and co-design approach we adopted. Because the seven design guidelines of the process model are considered simultaneously, it is difficult to pinpoint how an individual principle can be applied to a certain design decision. On the other hand, we hope to show how the design guidelines were considered, so we indicate some typical cases by putting the design guideline in brackets. For example, [DGa] means the design guideline "a" of "Exploiting the affordances of mobile technologies" was applied to the design decision.

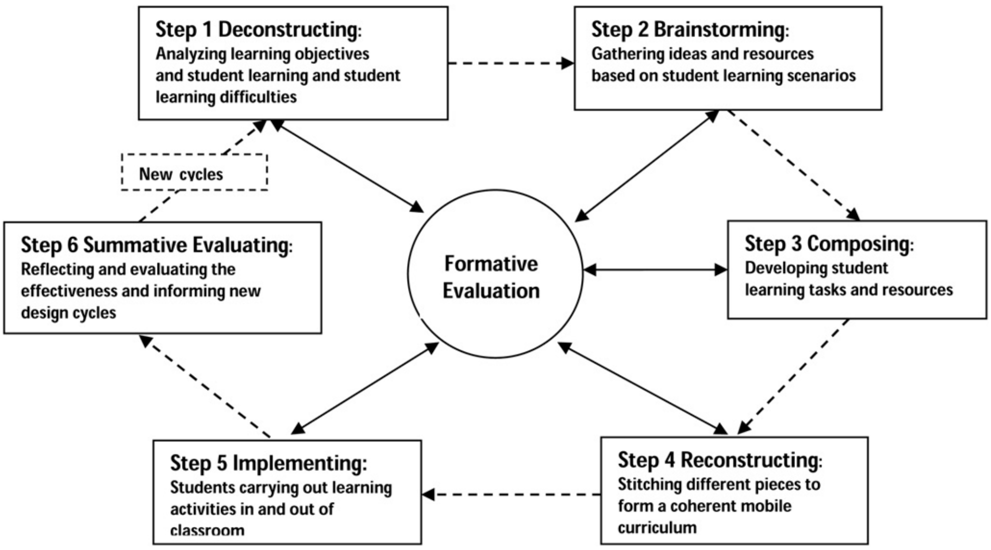


**Fig. 2.** A collective curriculum mobilization cycle.

### 5.1. *Step 1 Deconstructing: Analyzing learning objectives and student learning difficulties*

As mentioned before, in the P3 and 4 Science Syllabus (MOE, 2008), there are five themes: *Diversity, Cycles, Systems,* Energy and *Interaction*. *Diversity* is the first theme we deconstructed. As such, our first task was to identify the overarching goals. The diversity theme has the following short description in the Singapore Primary Science Syllabus:

> "Students should appreciate that there is a great variety of living and non-living things in the world. The study of the diversity in the world will allow students to appreciate the importance and necessity of maintaining it. Man seeks to organize the great variety of living and non-living things to better understand the world in which he lives. There are common threads that connect all living things and unifying factors in the diversity of non-living things that help him to classify them."(MOE, 2008, p. 5)

From this short description, we identified that the key process skill the students has to acquire in order to achieve the specific learning objectives is classification. Further to this step, we synthesized the 79 specific learning objectives across 7 topics and identified that the key

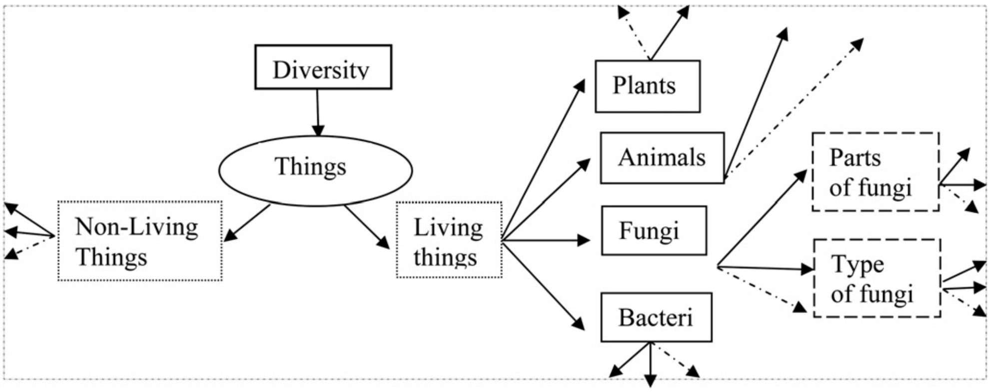


**Fig. 3.** Partial view of the concept map of diversity.

ideas the students need to learn are the characteristics and purposes of living and non-living things. With these in mind, the overarching goal was identified as: *Classification of living and non-living things according to their characteristics and purposes*.

"Deconstructing" means to understand the key learning points in a theme, to make the relationship between the topics and concepts visible to teachers and students, and to seek coherence in the mobile curriculum. Deconstructing is done by co-constructing a web of concepts to illustrate the interrelationships between concepts. Fig. 3 is a partial view of a map of the concepts showing the relationship of the topics and concepts deconstructed for Diversity. We design for the learning objectives defined and specified in the science syllabus in regard to *Knowledge, Understanding and Application*, *Skills and Processes*, *Ethics and Attitudes.* Table 5 shows some of learning objectives. More detailed activities with consideration of the overarching learning objectives are specified in detailed lesson plans. The flow can be seen in Appendix. Lesson plans are embedded with more details to spell out the learning objectives, activities, time allocation, related files, such as student workbook activities, and resources the teacher and students might look further if interested.

**Table 5**
Specification of learning outcomes in science theme of "diversity".

| Learning Outcomes in MOE Primary Science Syllabus 2008 | | |
|---|---|---|
| Knowledge, understanding, and application | Skills and processes | Ethics and attitudes |
| Diversity of living and non-living things | | |
| Describe the characteristics of living things.<br>-Need water, food and air to survive<br>-Grow, respond and reproduce | Observe a variety of living and non-living things and infer differences between them | Show curiosity in exploring the surrounding living and non-living things |
| Recognise some broad groups of living things.<br>-Plants (e.g. flowering, non-flowering)<br>-Animals (e.g. birds, fish, insects, mammals)<br>-Fungi (e.g. mushroom, yeast)<br>-bacteria | Classify living things into broad groups (plants and animals) based on similarities and differences of common observable characteristics | Value individual effort and team work |

Fig. 3 shows the partial view of the concept map on diversity using the attribute of "characteristics of things" for classification. We used the concept map to facilitate the deconstruction of the topical content. The whole map shows one of the possible ways to classify things according to their characteristics. For each node on the map, characteristic analysis is the first strategy that the curriculum task force employed to deconstruct the content. We used different shapes and line patterns to indicate the levels of concepts. Boxes of the same shape and line patterns belong to the same level of abstraction when classifying living and non-living things. The arrows show the expansion of concepts. The arrows of dashed line indicate that each concept can be linked to more concepts. The biggest square with dashed lines indicates that we were only able to show part of the whole concept map and there are more links to other nodes and ideas.

We also take into account the teachers' readiness in the design process. Before embarking on the design of a mobilized curriculum, teachers need to understand the overall objectives and learning points of a module in order to develop lessons that can integrate the affordances of the mobile devices coherently. To redesign a mobilized curriculum, emphasis should be placed on synthesizing the understanding of what should be taught as well as the cognizance of the affordances of the mobile devices. Students may face challenges that emanate from their limited exposure with the inquiry process, limited pool of scientific vocabulary, and naive or evolving conceptions of the science concepts. Last but not least, existing learning and teaching resources were also reviewed to ensure that the mobilized curriculum could be fully integrated into the school plans. Teachers should be freed from the expectations of teaching every single skill and piece of knowledge presented in the textbook. To do this, deconstructing the theme will enable the teachers to focus on the overarching goal to help students achieve desired outcomes efficiently. This source of efficiency lies in the teachers' ability to search for resources to help students connect their learning experiences both within and across the topics encapsulated in the diversity theme [DGg].

The other outcome of deconstruction was the identification of related topics and the epiphany of how materials could be re-sequenced based on students' learning difficulties. For example, our observation showed that students did not necessarily make connection between the general characteristics of living things to specific cases like fungi. Therefore, we designed a comparison table for students to compare and contrast the characteristics (Fig. 4). This pushed for a restructuring of the learning content presented in the textbook. Although we were still constrained by the assessment timeline, we were able to achieve a better flow of learning. This has helped the teachers to see the rationale and benefits of linking related topics.

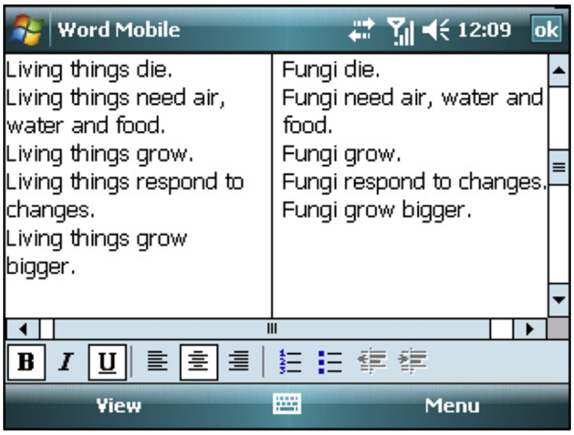


**Fig. 4.** Comparison table of fungi and living things on the smartphone.

### 5.2. *Step 2 Brainstorming: Gathering ideas and resources based on student learning scenarios*

The next step in our process involves the creation of learning scenario by the task force for the MLE activities. The scenario typically defines the learning experiences that the teachers want the students to have and what the students need to achieve. Because of time constrain, the finalization of the design and the uploading of the lesson materials were mostly done by the form teacher, Grace [DGf]. Using the students' learning objectives as a starting point, our design was more focused on the learning processes (Krajcik, McNeill, & Reiser, 2008). Students learned by participating in classroom activities, deciphering the concepts in the textbooks, and corroborating information from Internet resources. They were involved in the inquiry process in both formal and informal settings which include observing things around them, collecting data for online sharing and working in groups to reach consensus on their description of the characteristics of living and non-living things; as well as consolidating their learning by creating a digital animation to showcase the characteristics of fungi.

There were formative and summative assessments involved in the process. The possible misconceptions of the topic were also identified and addressed in the activity designs. For example, in the scenario planning for the MLE on fungi, the teachers wanted to provide students with thought-provoking and attention-arresting triggers. A YouTube video clip about *fungi* was chosen for such a motivating and anchoring event (Appendix, Activity 2) [DGa]. After this introduction, the task force wanted to assess the students' prior knowledge and provided scaffolding to help students engage in self-directed learning. They also wanted to make sure that the students were able to relate their learning in this topic to the prior concepts learned in plants and living things. They wanted the students to draw connections among these topics and relate them to the theme of diversity. The teachers did not want to just impart knowledge, but wanted the students to observe and actively conduct research. One way to serve the purpose was to ask students to fill in and frequently update their KWL files (Appendix, Activity 1) [DGg]. Fig. 5 is such an example.

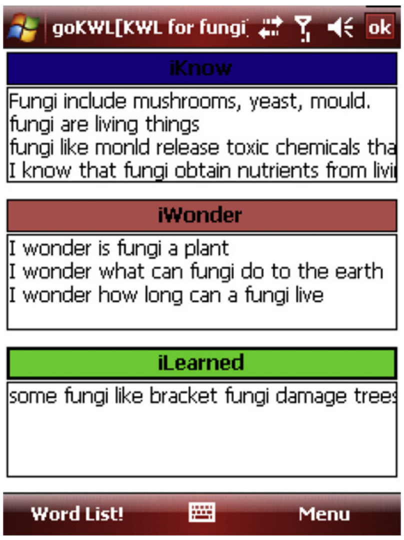


**Fig. 5.** KWL-Fungi.

As part of inquiry learning, the task force wanted the students to work in groups to conduct an experiment on bread mold. The students had to record their observations in writing and at the same time take pictures as evidence of data collection. The attempt experienced limited success as the students were new to the concepts of "variables" and "controls" [DGc]. The teachers also wanted the students to engage in collaborative learning using the jigsaw method (Appendix, Activity 3) [DGe]. To bring closure, they proposed that the students identify examples of fungi in their environment. In order to motivate the students, they called the activity as "grand challenge" (Appendix, Activity 6) [DGc]. After completing a host of activities in the MLE, Grace wanted to be sure that the students could answer 'examination-style' questions independently. Being aware that her role was to facilitate and monitor students' learning, Grace refrained from asking leading questions and dishing out answers. She also has to build upon the students' current knowledge and design scaffolds to help students expand their knowledge. The teachers identified possible misconceptions the students might have and planned for activities to surface and address these misconceptions. Such learning gaps were singled out based on Grace's professional discretion, researchers' prolonged classroom observations and the analysis of students' artifacts.

### 5.3. *Step 3 Composing: Developing student learning tasks and resources*

After the brainstorming session, the task force selected relevant ideas for further development. Members volunteered to work on specific aspects of selected ideas. For the topic of fungi, the tasks looked like these:

1. To create a presentation that will impress the students with the idea of diversity of fungi. The teacher has to make this presentation visually attractive (e.g. Appendix, Activity 1).
2. To find a multimedia resource that introduces the students to the characteristics of fungi as a living thing (e.g. Appendix, Activity 2).
3. To create a resource to help students research the characteristics of fungi using the jigsaw method. This activity cannot be more than 1 hour (e.g. Appendix, Activity 3 and Table 6).
4. To create an activity to help students to compare and contrast fungi and plants. The students should be able to create a concept map of fungi after this activity (e.g. Appendix, Activity 4 & 5).
5. To create opportunities for students to apply what they have learned about fungi in their daily experiences (e.g. Appendix, Activity 6).

**Table 6**
Tasks that make a student an "expert" on one thing of fungi.

| | |
|---|---|
| Number 1: | Physical characteristics – what do fungi look like? |
| Number 2,7: | Reproduction – How do fungi reproduce? |
| Number 3,8: | Growth – What conditions do fungi need to grow? |
| Number 4,9: | Food – What do fungi 'eat'? |
| Number 5: | Size –What are the examples of fungi that can be seen and cannot be seen by our eyes |
| Number 6: | Types of fungi – What are the examples of useful and harmful fungi? |

The composing stages entail creative thinking and good understanding of a) content; b) student learning difficulties; c) the affordances of the smartphone and d) the related applications. Again, it is a process of teacher learning because researchers would handhold the teachers on integrating the affordances of the mobile technology within the MILE framework [DGf].

### 5.4. *Step 4 Reconstructing: Stitching different pieces to form a coherent mobile curriculum*

In reconstructing, we developed the flow of events and learning activities according to the desired outcomes delineated in the learning scenarios. We also stated the desired pedagogies and how the teacher should facilitate the learning. Finally, the resources for the students were packaged in an MLE project and disseminated to the students through the GoManage server.

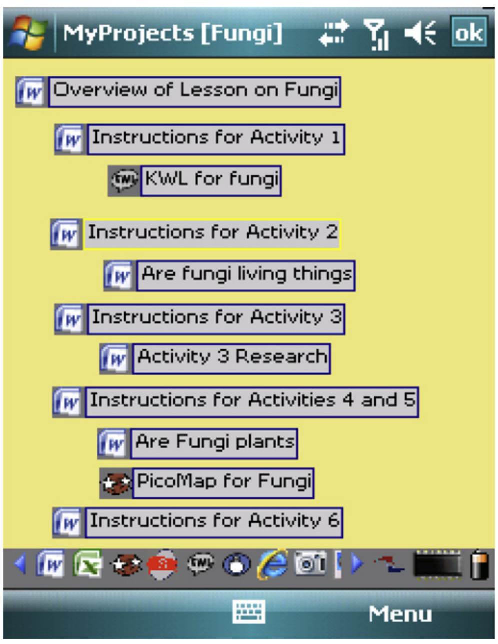


**Fig. 6.** Learning instructions and tasks of a mini-project – Fungi.

Although the introduction of tasks suggested a sequence of activities which warranted the coherence and logical flow of inquiry process, students had more flexibility in controlling their own pace and sequence for the task because they could open the files in any order and freely switch among the different files (e.g. Word, Excel, Sketchy, Picomap, and KWL). Fig. 6 shows instructions of a mini-project on fungi. The students were required to complete the activities in the project folder by the due dates. They either worked in groups or independently. It should be noted that the coherence of the flow of teaching depended a lot on the teacher Grace herself. She was happy with the student-centered approach because she could free up lecture time to observe student as well as group work, answer student questions, and unearth student learning difficulties. She was able to adjust her pace of teaching to address student learning difficulties in a timely manner. We understood that to form a coherent mobile curriculum was easily said than done. Our revision to the current materials will also be based on our analysis of data collected, such as classroom videos and student artifacts.

### 5.5. Step 5 Implementing: Students carrying out learning activities in and out of classroom

The teachers distributed the MLE lesson package to the students' handhelds through the GoManage Server application. This enables learning to take place everywhere and anytime. The students took the initiative to read the lesson overview before the teachers start the lesson. By reading the overview, the students had a broad idea of their learning activities and were also aware of the learning objectives that they had to achieve. This document also informed them about the schedule and deadlines of the tasks they had to complete.

As researchers, we made observations and interventions during class time. Together with the class teacher, improvisation and fine-tuning were done during class or after class. We also provided timely feedback to the class teacher to help her improve her classroom management and facilitation skills. More importantly, we observed how the students responded to the activity design. In addition, we collected students' artifacts to triangulate our findings about the impact of MLE lessons on student learning. These data will serve to inform the iterative design of our next cycle.

The central emphasis of our design is to accentuate the teachers' role as a facilitator (e.g. Fig. 7). As part of the professional development efforts, we helped teachers to get acquainted with the notion of facilitation by providing role modeling and recommending specific pedagogies to promulgate facilitation. In some cases, we visualized the learning scenarios in class and scripted what the teacher could take note of to enhance the efficacy of the process. We monitored the students' learning progress both in class and out of class on GoManage by reviewing what they had uploaded to their private online spaces. We identified learning milestones, misconceptions, and facilitation opportunities from our reviews and worked with the teacher to improve the students' learning experiences. Fig. 8 is one example about how teachers and researchers discover student misconceptions through studying a student concept map. Activities were not confined to the classroom. We had extended students' learning spaces to their homes and social settings to find out how students used their smartphone and its applications beyond the classroom setting.


**Fig. 7.** Teacher Grace talked to a student group.

### 5.6. Step 6 Evaluating: Reflecting and evaluating the effectiveness and informing new design cycles

The curriculum task force met on a weekly basis; and there were two researchers stationed in the school for at least three days a week to observe the science lessons. They met, emailed, and/or talked with the Grace almost every day; hence, reflection and evaluation of the lessons were carried out daily. Researchers and participating teachers discussed the results of their formative assessment weekly. Researchers reported classroom observations and selected students' work for analysis almost after every lesson. A typical lesson lasted one or two periods (each period is half an hour), but sometimes it could be longer. This is so as Grace taught English, Mathematics and Science and thus enjoys some latitude in adjusting the schedule of lessons across the three subjects. In fact there were many occasions where lessons were fine tuned or improvised during the enactment of lesson. In general, the total teaching time remains unchanged relatively, but there was a significant increase in the preparation time for mobilized lessons. It should note that once this preparation was done, the revision to mobilized lessons can be easily adopted by other teachers.

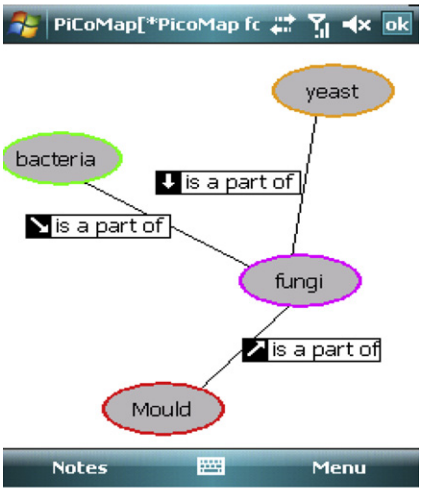


**Fig. 8.** A student's concept map

## 6. Teacher and student changes as results of the enacted curriculum

Given the space limitation and focus of this paper, which is to describe the consideration and process of how to "mobilize" the primary three science curriculum, we may not be able to provide detailed account of the impact of the enacted curriculum. Nevertheless, we present some data to show the changes in general. An overview is provided in Table 7. Our data sources were mainly field notes and weekly meeting minutes when the two researchers and others reported their weekly interaction with teachers and students, and observation of science lessons. Classroom videos, photos, and student artifacts were used when needed to provide evidence for our assertions. An analytical framework is also shown in Table 7. The indicators of change were mainly from the fungi unit. The results were selected and scanned by two researchers and the class teacher in alignment with their observation and expected learning objectives for each unit. They reached consensus by constant exchange of ideas and discussion because they always work together. "Initial intention" reviews the major consideration of the design guideline. As mentioned before, researchers followed the class throughout the year to collect data before and after the enactment of the co-designed curriculum. We try to connect our design guidelines and the results to compare and contrast student and the teacher changes before and after the enactment of mobilized science curriculum.

Table 8 is an overview of our mobilized curriculum development and enactment schedule. It should be noted that the co-design of curriculum and teacher professional development had started before year 2009. There was also an "informal" learning sub-group of our "seamless" learning project team that visited target students to their homes regularly. The purpose was to study the possible linkages between school curriculum and students' emergent learning mediated by the smartphone outside the class context. Our preliminary results were mainly gathered from classroom observations and designed field trips.

**Table 7**
An overview of teacher and student changes as a result of the enacted curriculum.

| Design guideline | Initial intention | Indicators of change | |
|---|---|---|---|
| | | Before | After |
| a. Exploiting the affordances of mobile technologies | The affordances and pedagogical consideration were listed in Table 2. | Students used mainly worksheets | Students produced artifacts on the smartphone and uploaded them online |
| b. Use the smartphone as a learning hub to integrate formal and informal learning activities | Learning everywhere all the time; the smartphone and applications as personal learning management system. | There was no single place where students put all their work and resources | Students take the phone with them 24/7. Students could continue to work from class or start their own learning projects |
| c. Design student-centered inquiry-based learning activities | Inquiry-based learning prepares students to be independent and lifelong learners. | Students seldom had a chance to initiate their own learning | Students had tools to post questions, collect data, analyze data, write reports in a timely manner |
| d. Making use of community support and resources | Learning becomes contextualized, authentic, situated, and thus meaningful. | Not all students had access to the resources | Going for field trips to science centers, farms, etc. became part of the curriculum with mobile learning |
| e. Facilitate collaborative knowledge building | Students create, provide feedback, and revise their understanding through multiple representations with multimodalities. | It was more difficult to co-construct knowledge | Exchanging ideas and making thinking visible and sharable was much easier |
| f. Support teachers to be good curriculum developers and facilitators | The co-design process as professional development for teachers and researchers to understand each other's perspectives | The teacher covered the textbook and led the class | The teacher had more time to look into student learning difficulties as a facilitator in mobile learning |
| g. Assess student learning formatively | Teachers and students reflect their teaching and learning by accessing student work, and provide/receive feedback in a timely manner | The teacher discovered student learning difficulties in assignments | The teacher usually could find out student learning difficulties in class and made adjustment to her teacher in a time manner |

**Table 8**
An overview of timeline and science topics in class for school year 2009.

| Time line | Term 1 before enactment | Term 1 after enactment | Short break | Term 2 | June holiday break | Term 3 | Short break | Term 4 | Dec. holiday break |
|---|---|---|---|---|---|---|---|---|---|
| Date | Jan. 3 –Feb. 19 | Feb. 19-Mar. 14 | Mar. 14 –22 | Mar. 15-May 29 | May 30 - June 28 | June 29 –Sept. 4 | Sept. 5–13 | Sept. 14 – Nov. 21 | Nov. 21-Dec. 31 |
| Formal class enactment Milestones | Tender for equipment; Administrative work to prepare experimental classes | Training; co-design curriculum; PD;*Living and Non-living Things* | | *Animals; Classifying Animals;Fungi and Bacteria; Material.* | | *What is a system Your Amazing body; Digestive system.* | | *Plants and their parts* | |
| Home visit arrangement | (Note: Visits were arranged once every month to 6 target student homes) | | | Home Visits in April and May | | Home Visits in July and August | | | Science Centre Visit |

Two researchers had observed all the science lessons and served as on-site supporters to work with the teacher for the enactment of the mobilized curriculum. Artifacts created by the students during the lessons were collected and archived. The artifacts comprise students' Sketchy animations, KWL, Mobile Word documents, and photos taken using the mobile devices. We interviewed a selected group of 10 students about a month after the use of the mobile devices in the class. We recorded each weekly professional development session with the teachers where they were involved in the lesson co-design with the researchers. We interviewed each teacher prior to the PD session. As the researchers worked closely with the teacher, we had informal conversations as the teacher shared her perspectives and reflections about the lesson design. In the following section, we present our preliminary findings as a result of the intervention. We use conventions to indicate our assertions. In order to highlight the connection between our design guidelines and the observed changes, we put the linkage in brackets [ ]. For example, if an outcome is more a result of design guideline a, we put [DGa] after the outcome.

### *6.1. Students were more engaged and motivated [DGa]*

The researchers observed a shift in the classroom behaviour after the introduction of the mobile devices. Initially, it was difficult for the teacher to keep the class in order. After introducing mobile learning, students became more engaged and motivated in completing their tasks. As seen in Fig. 9, some students did not want to stop their tasks even when their smartphone was being charged. When the batteries of some of the students' devices became low, they organised themselves orderly in deciding who should charge the devices. Although there was limited number of chargers, the children waited patiently for their turn. In addition, the students were self disciplined and they managed to complete their tasks independently without teacher supervision, as seen in Fig. 10.

**Fig. 9.** Students work on their task while charging the devices

### *6.2. Students were engaged in inquiry-based learning [DGb] [DGc] [DGd] [DGg]*

Students were able to conduct research by formulating questions, conducting online search, collecting data, producing quality animations, concept maps, and other digital artifacts to reflect their understanding as well as negotiate meanings collectively. For example, after we modeled how to compare the characteristics of living things and fungi as shown in Fig. 4, students were able to design their own comparison tables. The students were engaged in using their inquiry process skills such as finding evidences, evaluating what they have found, and making comparisons.

The use of educational applications also augments Grace's ability to identify students' misconceptions. To illustrate, in a lesson where the Sketchy was used, a student drew a spider as an insect with six legs and a pair of antennae as shown in Fig. 11. It was only when they represent (pictorial, textual, or even verbal) scientific concepts in different modes that the teachers are able to evaluate and provide

**Fig. 10.** Students continue working on their tasks without the presence of teachers

feedback to students. There was an emergence of participatory learning culture among the students when they communicated ideas, shared learning tasks, and sent their artifacts to each other for critique [DGg].

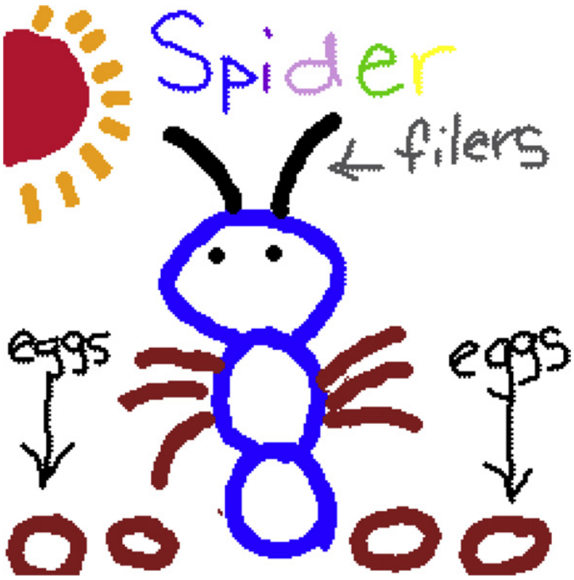


**Fig. 11.** A sketchy animation page of a student's misconception of insects.

### 6.3. Students showed significant improvement in their year-end science exam

To examine the effect of mobilized curriculum on students' traditional assessment, we conducted Analysis of Variance to compare the 6 mixed ability classes' year-end Science exam results. The mean and standard deviation of each class' exam scores are shown in Table 8. There were significant differences on the year-end exam scores among the 6 classes ($F(5,345) = 63.228$, $p < 0.01$). To remove the confounding effects of pre-existing individualscore differences, we conducted one-way Analysis of Covariate (ANCOVA) to examine the P3 year-end science exam score (dependent variable) differences across 6 classes (independent variable) using the science scores from the practice test (before the first mobilized lesson) as the covariate. The results are shown in Table 9.

The ANCOVA results showed that there is a significant difference on year-end science exam scores among the 6 mixed ability classes after controlling the exam score before the introduction of mobilized lessons ($F(5,345) = 31.619$, $p < 0.01$). The class difference explains 41.1% of the variance in the year-end exam scores. The intervention class 305 had the highest exam scores among all the mixed ability classes. Thus the mixed ability class with the mobilized lesson intervention performed better in the traditional Science assessment than the classes without the intervention.

### 6.4. Students showed signs of collaborative and self-directed learning [DGe]

Students could conduct independent research online because they had unlimited data plan for their phone computers. Some students searched for videos relevant to classroom learning from YouTube. Questions raised by the students during class focus more on the content of

**Table 9**
ANCOVA on year-end science exam scores across 6 mixed ability classes when holding the exam scores before the introduction of mobilized lessons constant.

| Class | *N* | Mean Total year-end score | SD | Adjusted mean Total year-end score |
|---|---|---|---|---|
| 304 | 39 | 75.49 | 7.786 | 71.50 |
| **305** | **39** | **76.67** | **8.588** | **74.11** |
| 306 | 41 | 71.63 | 8.952 | 68.22 |
| 307 | 36 | 41.36 | 16.507 | 48.90 |
| 308 | 40 | 55.95 | 12.704 | 59.31 |
| 309 | 39 | 72.13 | 7.706 | 71.87 |

the lesson. As compared to the pre-intervention stage where questions were centered around the clarification of teacher's instructions, the changes in the nature of the questions could be attributed to students engaging in their independent research of the subject. We have introduced KWL for students to record their thinking over time. It is also a mechanism to help the teacher make formative assessment. Student questions in *What I Want to Know* reflect deeper thinking and are more relevant to what they were doing. Figs. 5, 12 and 13 show some of the questions raised by student Jeremy in his KWL. He shared with the researchers that he liked to use KWL to monitor his own learning progress. Some students have explored new applications for learning purposes. We consider behaviors such as students formulating their own questions and feeling less inhibited when asking questions (that might be deemed as "stupid" by their peers and their teacher) as very significant cultural changes. As shown in Fig. 7, students often work in small groups of four or five. They had to complete tasks within certain amount of time following instruction on their smartphones. They exchanged their phones to receive quick feedback to their work in progress. Jigsaw approach was employed occasionally to advance computer supported collaboration. These are the most significant indicators of pedagogical change towards collective knowledge construction.


**Fig. 12.** KWL-mammals.

### 6.5. *The teacher positioned herself as a facilitator [DGf]*

There were obvious changes in class structure when implementing the mobilized curriculum. For the class teacher, she used to be under pressure to cover the essential learning points through teacher-centered approach. Now she was able to switch her didactic teaching to student-centered learning. She was inclined to give students more time to construct their understanding rather than feeding them with information. With more time to observe students learning with mobile devices, she learned to identify student learning difficulties when she facilitated student learning (see Fig. 7). The use of the designed MLE lessons gave the teacher more breathing space and she was able to focus on the natural flow of the lessons. In the past, she was task-oriented and aimed to finish predefined drill-and-practice activities in stipulated time. When implementing MLE lessons, she instructed when the situation called for it and she spent more time facilitating the learning processes rather than providing answers. As a result of using the redesigned curriculum using the mobile devices, the teacher shared with the researcher that she had more time to reflect on her lessons even during class. She could think on her feet and improvise on the lessons in real time.

### 6.6. *The teacher became more confident and knowledgeable in mobile learning*

In an interview with researchers, the teacher recalled her experience since she joined the project and worked with the curriculum development task force, co-designed and implemented the mobilized curricula. She acknowledged that she herself learned much from the experience of being involved in designing the mobilized curriculum as well as enacting it in class:

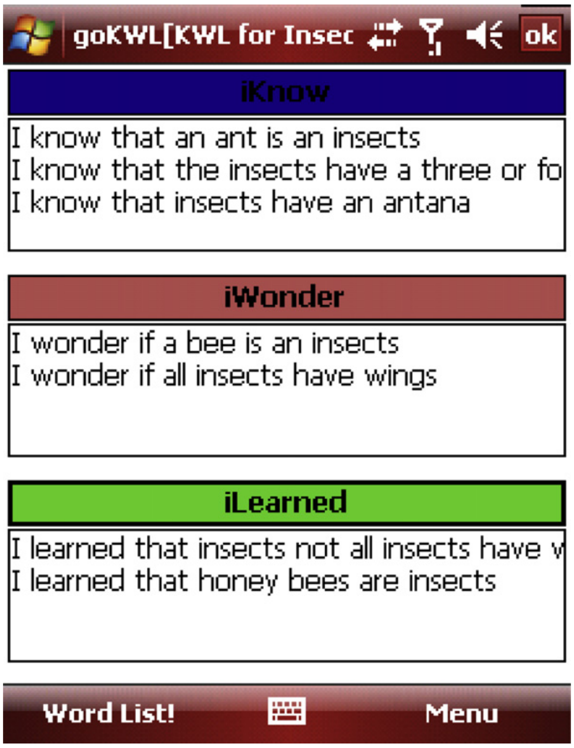


**Fig. 13.** KWL-insects.

"I feel I do not have enough content knowledge (before the project)…I would say I have gained some content knowledge…through the PD sessions…it is more fruitful than being a trainee at NIE (the teacher training institute in Singapore) …"
"In the past, I taught chapter by chapter…but I did not know I can actually change the order of the content and teach in a different way…"

She further elaborated changes in herself:

"…at the beginning (of the project)…I felt stressful…(now) when I come to class, the stress did not come from content…they came from different sources…it was about technology or questions from the students that I could not predict ….but I feel more confident…I have more content knowledge…".
"In the past, I had to respond to a student's question, so I (sometime) gave an answer anyway even I was not so sure…now, if I do not know, I will say 'I do not know'…because otherwise a student might find the answer (by searching the Internet on their smartphone) and get back to me immediately…" "I changed my mindset…now I feel I am learning with the students…it is OK to say I do not know…"

In summary, the teacher acknowledged that the curriculum co-designing experience helped her to prepare her teaching in terms of subject knowledge, student learning difficulties, and the use of technologies. The co-design process also allowed researchers to understand tensions between the seamless learning approach and existing concerns of the teacher, such as assessment, in order to develop feasible and evolutionary strategies towards a fundamental switch of pedagogy.

## 7. Discussion and conclusion

In this paper, we have discussed why we need to redesign the current primary three science curriculum, and how we have deconstructed and reconstructed the curriculum in order to harness the affordances of mobile technologies for students' meaningful learning. We have articulated our proposed design process cycle in transforming the current curriculum into mobilized learning activities, and shared our experiences in using this framework to design P3 science activities. We have begun to develop mobilized curricula as the first step to realize the notion of seamless learning using mobile technology. The mobile curriculum for the theme of *Diversity* has been implemented while more units are currently being developed. We exploited the mobile technologies to facilitate student communication, collaboration, and learning because they are not "foreign" things but part of students' life. The new mobilized learning activities are needed to help teachers use technology to facilitate student-centered learning but not to use technology to conduct drill-and-practice lessons. They are aimed at providing a holistic learning scenario to engage students in inquiry learning. They also enable the teacher to blend technology into core teaching and learning rather than to use technologies as add-ons to their routine practices.

There has been a proliferation of studies on how to take advantage of mobile learning technology for learning purposes. This paper intends to contribute to the literature by elaborating the challenges that we are facing and describing the deconstructing and reconstructing process when we are *mobilizing* the primary three science curriculum. It should be noted that when teachers and students developed their "new" teaching and learning routines, there could be activities that students were able to do without the smartphone computers. Our intention was not to make teaching and learning to be bounded to the smartphones but to promote student-centered and inquiry-based learning. The smartphone was an enabler to stimulate the transformation of teaching and learning. Our study contributes to the literature in the following way:

a. Our goal was to transform school routine teaching and learning practices; in this case, we mobilized a whole level of primary school science curriculum, made mobile learning the routine for the science lessons, and prepared students for out-of-classroom self-directed learning;
b. The design, implementation, and evaluation were done simultaneously so that we were able to improve our curriculum design and implementation in a timely manner;
c. This is a longitudinal study of a class having mobilized lessons over a period of two years.

Papers like this have been scarce. We have observed some positive changes in teacher teaching and student learning and their attitudes towards using mobile technologies for learning purposes. Students were very engaged in the inquiry tasks such as data collection and group work in artifact production. Additional challenges to implementing mobilized curricula in the classroom include improving the teacher's facilitation skills, creating MLE activities that require more opportunities for collaboration amongst students, and monitoring the achievement of specific learning objectives more systematically. The formative assessment like the use of rubrics by teachers and even the students themselves for learning purposes will be emphasized in our follow-up research activities. We have been working on designing, implementing, and revising our curriculum for a year. We plan to follow the experimental class for another year and continue developing, implementing, and evaluating primary four science curriculum. Inasmuch as there is a paucity of methodologies for designing inquiry-based curriculum in the literature, our efforts at the curriculum redesign were more interactive than ordered, more exploratory than rule-following, and more inventive than we had ever wanted. After we created the inquiry-based, mobile-device-based curriculum units like the fungi unit, we stepped back and developed a more articulated set of steps that captures the essence of our development process.

Depending on the available time for teaching a topic and the nature of the topic, there were always broader learning goals that guided the curriculum design: Inquiry-based learning, self-directed learning, and collaborative learning. However, we are still in the process of prioritizing the detailed objectives for each of the learning goals in terms of preparing students to be able to take initiative to demonstrate competence on the broader learning goals. There have been changes to the members of the curriculum task force so that we could involve the heads of the science and English departments in the school. This shows the school's commitment to the sustaining and scaling up of our collaboration. The following are some of the tasks for future work: a) develop systematic formative assessment; b) prepare and encourage out of classroom self-directed and collaborative learning; c) scale up to more classes; and d) develop a sustainable model in terms of curriculum development, teacher professional development, and addressing school-based and alternative assessment.

Our work on mobilizing science lessons was situated in the broader context of constructing "seamless learning" environments to bridge formal and informal learning (Chan et al., 2006; Looi et al., 2008). Our longer-term intention is to bridge student formal and informal learning through our mobilized curriculum by fostering self-regulated learning and providing necessary inquiry-based science learning tools such as the MLE applications. Our future work will look at the use of the mobile technologies beyond classroom learning so that we extend our work from classroom learning to the space of seamless and longitudinal use of mobile technologies.

## Acknowledgements

This work was supported in part by the Singapore National Research Foundation (Grant #: NRF2007IDM-IDM005-021). We thank the experimental school, teachers, and students for their collaboration. We thank other project team members for their inputs to enhance the paper, especially Yancy Toh for her editing. We would also like to thank the anonymous reviewers for their constructive feedback to improve the quality of the paper.

## Appendix: Lesson procedure (A microsoft mobile word file).

**Activity 1:** Look at the slides presented by the teacher and understand that that fungi come in different shapes, sizes, and colour.

Instructions for Activity 1:
1. Look at the slides presented by the teacher.
2. Observe the fungi presented.
3. **In class**, spend **5 min** to write down what you have observed in 'I know' in the KWL.
4. During your **free time**, write down what are the other things that you know about fungi.
5. Think about what you want to find out about fungi in 'iWonder' in the KWL during your **free time**.
6. Do research on your PDA and find the answers to your questions. Update the KWL daily to see how much you have learned and record what you want to find out. (Due on 27 Apr 09)

**Activity 2:** Watch a video on Fungi on YouTube and complete activity on *Are Fungi Living Things?* (Due on 15 Apr 09)

Instructions for Activity 2:
1. You will be given **30 min** to watch the video and complete worksheet- Are fungi living things?
2. Watch a video on Fungi on YouTube individually.
3. Connect the ear piece to your phone before you play the video.
4. Listen carefully to the narration in the video.
5. You can watch the video again if you need to.
6. Complete the worksheet- Are fungi living things?
7. You can discuss with your partner but please be considerate and whisper.

8. Click on this link to watch the video. http://www.youtube.com/watch?v=puDkLFcCZyI,http://www.youtube.com/watch?v=qDwgSWDqKoQ

**Activity 3:** Work with your group mates in a Jigsaw activity to research more about the characteristics of fungi. **(Due on 21 Apr 09)**

Instructions for Activity 3: What are fungi? Let's find them out

Work with your group mates in a Jigsaw activity to research more about the characteristics of fungi.

Part 1: Independent Research during your free time In the jigsaw activity, you have to do independent research during your free time. You will be in charge of researching on one characteristic of Fungus according to the number on the back of your PDA. You can find your research topic below.

You are the expert in your research topic and your group mates depend on you to provide as much accurate information as you can.

Part 2: Group Discussion and Presentation in class Your teacher will arrange for you to sit together with your classmates who had research on the same topic. This will be the expert group. In your expert groups, discuss and share the information that you have found with one another. Please take turns to speak. Listen to your friends quietly. *Everyone* in the expert group have to share what they have found out. Record what you have learned from your fellow experts in the Activity Worksheet 3. You can ask questions after your friends have stopped talking. The teacher will select, at random, a representative from your group to present your group findings to the class.

Part 3: File exchange among members in home group during your free time 1. Home group is your original group. 2. You and your group mates have researched on different characteristics and learned from other expert. 3. Now you are ready to share what you have learned and recorded on Activity Worksheet 3. 4. During your free time, email this file to your group mates so that they can learn from your research.

**Activity 4:** Complete activity on *Are fungi plants?* **(Due on 22 Apr 09)**

**Activity 5:** Complete a PicoMap to show your learning on Fungi **(Due on 23 Apr 09)**

Instructions for Activities 4 and 5: 1

**During your free time,** complete activities 4 and 5 **independently**. 2. You can discuss with your friends but please do not copy from one another. 3. You can refer to your Science Textbook for reference. 4. You can also use your PDA to help you with the research.

**Activity 6:** Play the role of a Fungi detective in the Grand Challenge. **(Due on 27 Apr 09)**

Instructions for Activity 6- Fungi Detective Grand Challenge

You have learned a lot about fungi in your research and from your friends and teacher. Now it is time to put your knowledge into practical use.

In this Grand Challenge, we want you to be a **Fungi Detective**!

Use the camera function on your PDA and take pictures of fungi in the following: 1) Toilet 2) Handbags 3) Human body 4) Food 5) Clothes 6) Plants 7) Walls in the school 8) Field 9) Rotting log 10) Any other places.

*Make sure you use the 'S' resolution for your pictures. Import the pictures into the Fungi Project.

Please read the instruction pages carefully before you start any activities. If you have any questions, find answers with your PDA first before you seek help from your teacher.

## References


Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Gudzial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3 & 4), 369–398.

Chan, T.-W., Roschelle, J., Hsi, S., Kinshuk, Sharples, M., Brown, T., et al. (2006). One-to-one technology-enhanced learning: an opportunity for global research collaboration. *Research and Practice of Technology Enhanced Learning, 1*(1), 3–29.

Chen, W., Tan, N., Looi, C.-K., Zhang, B. H., & Seow, P. (2008). Handheld computers as cognitive tools: An environmental learning project in Singapore. *Research and Practice in Technology Enhanced Learning, 3*(3), 231–252.

Churchill, D., & Churchill, N. (2008). Educational affordances of PDAs: a study of a teacher's exploration of this technology. *Computers & Education, 50*(4), 1439–1450.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3–14.

de Jong, T. (2006). Computer simulations–Technological advances in inquiry learning. *Science, 312*, 532–533.

Forbes, C. T., & Davis, E. A. (2007). Beginning elementary teachers' learing through theuse of science curriculum materias: a longitudinal study. Paper presented at the Annual meeting of the National Association for Research in Science Teaching. Retrieved from. http://hi-ce.org/presentations/documents/Forbes_Davis_NARST2007.pdf.

Gibson, J. J. (1977). The theory of affordances. In R. Shaw, & J. Bransford (Eds.), *Perceiving, acting and knowing*. Hillsdale, NJ: Erlbaum.

Krajcik, J. S., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education, 92*(1), 1–32.

Kurti, A., Spikol, D., & Milrad, M. (2008). Bridging outdoors and indoors educational activities in schools with the support of mobile and positioning technologies. *International Journal of Mobile Learning and Organisation, 2*(2), 166–186.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Looi, C. K., Zhang, B. H., So, H. J., Chen, W., & Wong, L. H. (2008). *Leveraging Mobile Technology for Sustainable Seamless Learning in Singapore Schools*, National Research Foundation (NRF). Grant number: NRF207IDM-IDM005–021.

Looi, C.-K., Wong, L.-H., So, H.-J., Seow, P., Toh, Y., Chen, W., et al. (2009). Anatomy of a mobilized lesson: Learning my way. *Computers & Education, Online*.

Malcolm, J., Hodkinson, P., & Colley, H. (2003). The interrelationships between informal and formal learning. *Journal of Workplace Learning, 15*(7/8), 313–318.

MOE, Ministry of Education. (2008). Singapore science syllabus primary 2008. Retrieved from. www.moe.gov.sg/education/syllabuses/sciences/files/science-primary-2008.pdf.

Norris, C., & Soloway, E. (2008). Getting mobile handhelds help bring K-12 classrooms into the 21st century. *District Administration Magazine, July* Retrieved from http://www.districtadministration.com/viewarticlepf.aspx?articleid=1638.

Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.

OECD. (2003). *Problem solving for tomorrow's world – First measures of cross curricular competencies from PISA 2003: OECD*. Organization for Economic Cooperation and Development.

Patten, B., Sánchez, I. A., & Tangney, B. (2006). Designing collaborative, constructionist and contextual applications for handheld devices. *Computers & Education, 46*, 294–308.

Penuel, W. R., & Yarnall, L. (2005). Designing handheld software to support classroom assessment: analysis of conditions for teacher adoption. *Journal of Technology, Learning, and Assessment, 3*(5), 50–70.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning, 2*(1), 51–74.

Rogers, Y., & Price, S. (2008). The role of mobile devices in facilitating collaborative inquiry in situ. *Research and Practice in Technology Enhanced Learning, 3*(3), 209–229.
Roschelle, J., Patton, C., & Tatar, D. (2007). Designing networked handheld devices to enhance school learning. In M. Zelkowitz (Ed.), *Advances in computer, Vol. 70* (pp. 1–60).
Scanlon, E., Jones, A., & Waycott, J. (2005). Mobile technologies: prospects for their use in learning in informal science settings. *Journal of Interactive Media in Education, 25*.
Skills, P.f. s. C (2003). Learning for the 21st century: a Report and Mile guide for 21st century skills. Retrieved from. http://www.21stcenturyskills.org/images/stories/otherdocs/p21up_Report.pdf.
Spikol, D., Milrad, M., Maldonado, H., & Pea, R. (2009). *Integrating co-design practices into the development of mobile science collaboratories*. Paper presented at the The 9th IEEE International Conference on Advanced Learning Technologies (ICALT 2009).
Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *Journal of the Learning Sciences, 16*(3), 371–413.
Vahey, P., Tatar, D., & Roschelle, J. (2007). Using handheld technology to move between private and public interactions in the classroom. In M.v. t. Hooft, & K. Swan (Eds.), *Ubiquitous computing in education: Invisible technology, visible impact* (pp. 187–210). Mahwah, NJ: Lawrence Erlbaum Associates.
Wallace, R. M., Kupperman, J., Krajcik, J., & Soloway, E. (2000). Science on the web: students online in a sixth-grade classroom. *Journal of the Learning Sciences, 9*(1), 75–104.
Vavoula, G., Sharples, M., Rudman, P., Meek, J., & Lonsdale, P. (2009). Myartspace: Design and evaluation of support for learning with multimedia phones between classrooms and museums. *Computers and Education, 53*(2), 286–299.
Zhang, B. H., Wong, L. H., Seow, P., Chen, W., & Looi, C. K. (2009, May 25-28). "*Mobilizing" curriculum materials for seamless learning—Opportunities and challenges*. Paper presented at the Global Chinese Conference on Computers in Education, Taipei.

**BaoHui Zhang** is an Assistant Professor in the Learning Sciences and Technologies Academic Group (LST AG) and Learning Sciences Laboratory (LSL) at the National Institute of Education (NIE), Nanyang Technological University, Singapore. He has more than 20 years of K-12 and college teaching and research experience with technology supported inquiry-based science learning and science teacher education. He is an editorial board member of the International Journal of Science Education.

**Chee-Kit Looi** is Head of the Centre of Excellence in Learning Innovation of NIE. He has over two decades of experience with educational technology research in research institutes and universities. He is an editorial member of the International Journal on AI & Education and the International Journal on CSCL.

**Lung-Hsiang Wong** is an Assistant Professor in the LST AG and LSL at NIE, NTU. His research interests are ICT-enhanced Chinese Language learning, teachers' professional development, agent technology for learning, and mobile learning.

**Peter Seow** is a senior software engineer with the Learning Sciences Lab, National Institute of Education. He has over 10 years of industrial experience in leading projects, consulting and systems development.

**Gean Chia** is a Research Assistant in LSL at NIE, NTU.

**Wenli Chen** is an Assistant Professor in the LST AG and LSL at NIE, NTU. Her research interests and expertise are computer-mediated communication, virtual learning environment, mobile learning, and community of learners.

**So Hyo-Jeong** is an Assistant Professor in the LST AG and LSL at NIE, NTU. Her research focuses on designing interactive online learning environments, and students' scientific knowledge building through collaborative inquiry.

**Cathleen Norris** is Regents Professor, University of North Texas, USA.

**Elliot Soloway** is Arthur F. Thurnau Professor, University of Michigan, USA.