Original article

doi: 10.1111/j.1365-2729.2010.00390.x

1:1 mobile inquiry learning experience for primary science students: a study of learning effectiveness

C.-K. Looi,* B. Zhang,* W. Chen,* P. Seow,* G. Chia,* C. Norris† & E. Soloway‡

*Learning Sciences Lab, National Institute of Singapore, Singapore
†University of North Texas, TX, USA
‡University of Michigan, MI, USA

Abstract This paper presents the findings of a research project in which we transformed a primary (grade) 3 science curriculum for delivery via mobile technologies, and a teacher enacted the lessons over the 2009 academic year in a class in a primary school in Singapore. The students had a total of 21 weeks of the mobilized lessons in science, which were co-designed by teachers and researchers by tapping into the affordances of mobile technologies for supporting inquiry learning in and outside of class. We examine the learning effectiveness of the enacted mobilized science curriculum. The results show that among the six mixed-ability classes in primary (grade) 3 in the school, the experimental class performed better than other classes as measured by traditional assessments in the science subject. With mobilized lessons, students were found to learn science in personal, deep and engaging ways as well as developed positive attitudes towards mobile learning.

Keywords elementary education, improving classroom teaching, mobile learning, mobilized curriculum.

Introduction

Educational researchers and practitioners have long been advocating the notion of 1:1 computing, which means equipping students with personal mobile devices and enabling 24/7 access so that the devices can mediate their classroom as well as out-of-classroom learning. From a science education perspective, there have been interests in developing curricula that specifically consider the affordances of these mobile technologies. Various studies provide designs for supporting student inquiry-based learning using mobile technologies (e.g. Roschelle *et al*. 2007; Squire & Klopfer 2007; Chen *et al*. 2008; Spikol *et al*. 2009; Vavoula *et al*. 2009). Most of them were targeted towards a short unit or cycle of activity that lasts at most a few weeks and may not have to be part of a school's existing science curriculum. In contrast, the problem we are approaching is to make mobile technology an integral and essential element in a school's curriculum with the teacher and students using mobile technologies in a routine way for their weekly lessons.

The term 'mobilized lesson' is used 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 (Norris & Soloway 2008). A 'mobilized curriculum' is a transformation from a more content-centred and teacher-centred infrastructure to a systematic student-centred infrastructure that seeks to foster personalized learning and self-directed learning (Looi *et al*. 2009). In researching the potential of the pedagogical possibilities afforded by

Accepted: 6 August 2010
Correspondence: Chee-Kit Looi, Learning Sciences Lab, National Institute of Education, NTU, 1 Nanyang Walk, Singapore 637616. Email: cheekit.looi@nie.edu.sg

© 2010 Blackwell Publishing Ltd

harnessing mobile technologies, we transform the existing science curriculum for a grade level into a 'mobilized' curriculum. We conduct this design and evaluation in an experimental class for a whole year's worth of science curriculum. As this is embedded in the real-world context of ensuring no harm done to the class, we are cognizant that students in our experimental class take the same tests as other students in the same cohort. The mobilized curriculum is expected to address learning objectives in the existing curriculum that follows the existing curriculum schedule and yet affords the possibilities for deeper learning and engagement in science, and personalized learning across contexts.

Our consideration for the redesigned science curriculum is for it to be adoptable in real classrooms with average teachers and average students. Such a transformation of the existing science curriculum will have to plan for a gradual but fundamental change of the curriculum, and for it to be sustainable. The process will require much time and resources for the co-design of lessons, for teachers' professional development, for setting up the technology infrastructure, and for evaluating the enactment of the curriculum in the classroom.

In this paper, we report on our first year's results of this pilot test of 1 year's worth of science curriculum in an experimental class. The researchers work closely with the teachers to design the mobilized lessons to teach the curriculum by tapping into the affordances of mobile technologies for supporting inquiry learning in and outside of class. The students experience a total of 21 weeks of these mobilized science lessons. In the overall project, we examine student and teacher change through classroom observations, analysis of classroom videos, analysis of the artefacts produced by them using the mobile devices, their performances in the traditional assessments, and interviews with the teacher, students, and parents. In our research, we are interested in articulating the challenges and opportunities to promote student-centred science learning with the use of mobile devices. However, in this paper, we will just focus on discussing the findings for this research question: what is the learning effectiveness of the students' experiences of the mobile inquiry lessons in science? The organization of this paper is as follows: we describe (1) the long-term vision of our research and the role of technology; (2) related work in technology-enhanced and mobilized inquiry science lessons; (3) the mobilized science curriculum; (4) the research design; (5) our findings; and (6) discussion and conclusion.

Envisioning a 'seamless' learning environment and the role of technology

This work in 'mobilizing' the science curriculum is framed in the broader context of constructing 'seamless learning' environments to bridge formal and informal learning (Chan *et al*. 2006; Looi *et al*. 2010). Opportunities are sought to go beyond classroom learning and explore the continuous, pervasive, and longitudinal use of mobile technologies. Our aim is to design a curriculum that facilitates and scaffolds student-centred learning activities that encompass formal and informal settings, that is, in and out of the formal classroom.

We collaborate with a Singapore primary school to explore a sustainable model for integrating 1:1 mobile technology into student-centred, inquiry-based learning. We followed a mixed-ability class to first observe the teaching and learning practices in the class. A curriculum task force involving teachers and researchers worked together by meeting weekly to develop a methodology for designing science inquiry-based curriculum. The research work also included pilot-testing the resulting curricular materials in classroom settings. Quantitative and qualitative research methods were deployed for studying the experimental classrooms, while an ethnographic research approach was used to study several selected students from the class in their home. Our intent is to describe the broad range of planned and emergent activities that occurred in class and outside of class over 2 years.

The mobile device chosen was the smartphone computer HTC TyTn II (Taoyuan, Taiwan) which runs the Microsoft Windows Mobile 6 operating system. The software on the HTC smartphone includes a calculator, a calendar, mobile web Internet access, MS Windows Mobile Word, Excel, and PowerPoint, which provide the affordances of basic math computation, self-monitoring, online search, digital production, data collection, data storage and analysis, and presentation. Besides these standard productivity software, students and teachers needed explicit software support for the inquiry learning approach we were using in our curriculum design effort. Our inquiry learning approach is intended to provide instruction and learning designed around examination of real phenomena and the pursuit

© 2010 Blackwell Publishing Ltd

of significant questions formulated by both teachers and students (Dow 2000). For this, we selected the GoKnow MLE (Mobile Learning Environment) (Dallas, TX, USA) that supports our pedagogical philosophy and serves a malleable environment to support the specific inquiry-based teaching and learning strategies as transformations of the existing science curriculum.

Our learning design framework provides the flexibility for a teacher to tailor student learning by providing assignments and tasks that are appropriate to individuals' and/or subgroups' levels for personalized learning. With the tailored learning tasks, students can adopt different learning pathways by using different tools on the smartphones for their learning purposes. The affordances of the smartphone with GoKnow MLE environment that we are harnessing include:

- A smartphone with the MLE provides a student a 'hub' to integrate learning resources and activities.
- Students have immediate access to their smartphones 24/7 and their Internet-based electronic portfolios (supported by the GoManage web-hosted application accessible from the smartphone over the Internet) as a personal learning space.
- The smartphone with Internet access affords student communication and access to information.
- The smartphone and its applications enable the digital production of artefacts (e.g. concept maps and animation) by students that reflect their conceptual understanding, as well as facilitate the sharing, commenting, reflecting and revising of their knowledge.

Review of technology-enhanced inquiry science lessons

In this section, we take a closer look at recent projects in technology-enhanced inquiry science learning. One of these is the Personal Inquiry (PI) project (http://www.pi-project.ac.uk/), which aims to help school students learn the skills of modern science through a 'scripted inquiry learning' approach (Sharples 2009). Students aged 11–14 investigate a science topic with classmates by carrying out explorations between their classroom, homes and discovery centres, guided by a personal computer. The project investigates how effective inquiry learning can be enabled with technology across formal and informal settings. Learners are guided through a process of posing inquiry questions, gathering and assessing evidence, conducting experiments, and engaging in informed debate. Their activities will be based around the topic themes of Myself, My Environment, and My Community that involve them in investigating their health, diet and fitness, their immediate environment, and their wider surroundings.

Students will use a personal inquiry toolkit which comprises a software application, called an 'Activity Guide', together with the associated hardware support for conducting the inquiry (including a range of sensors for use in collecting data – such as temperature and wind speed) (Scanlon *et al*. 2009). The Activity Guide running on both Ultra Mobile PCs and regular desktop machines supports students in defining, organizing, and carrying out their inquiry. From the description of the system, we can feel the strong emphasis on students' taking responsibilities as well as ownership for their 'personal inquiry'.

The Learning Ecology through Technologies from Science for Global Outcomes Project aims to provide educational activities and tools for helping students participate in collaborative science inquiry involving local environmental data (Vogel *et al*. 2010; Wichmann *et al*. 2010). These data are collected, analysed, reflected on, and reported through mobile and sensor technologies. Handheld-based data collection probes are used to augment inquiry-based investigations with real-time data and visualizations. Maldonado and Pea (2010) report a 90-min water quality curriculum unit designed for 16–18-year-old students. The design emphasizes the use of the new tools for doing science – sensors for data capture, information visualization for data analysis, and low-cost mobile computers and accessories for field-based science.

The Science Created by You (SCY) project aims to provide inquiry in science education by developing a flexible, open-ended learning environment that truly engages and empowers adolescent learners between 12 and 18 years old (SCY, n.d.). In this learning environment, called SCY Lab, students embark on authentic missions that can be completed through constructive and productive learning activities. Students work individually and collaboratively on 'missions' which are guided by a general socio-scientific question (for example, 'how can we produce healthier milk?'). Fulfilling the mission requires a combination of knowledge from different domains (e.g. physics and mathematics, or biology and engineering).

© 2010 Blackwell Publishing Ltd

Learners perform science inquiry by searching for information, doing research, discussing and collaborating with others. These activities require them to produce artefacts such as small notes, reports of measurements, computer models of the situations, drawings, designs and reports. Mobile devices like data loggers can be used for collecting data from real environment or experimental situations. These artefacts form the basis for organizing the work, to monitor progress and to collaborate with others. The SCY Lab is the main place where learners will see, create, edit and share their artefacts (de Jong *et al*. 2009).

Our initiative as reported in this paper shares similar goals as the above three projects in engaging the students in authentic science inquiry. We note some differences too. Our students were primary three students while the target audience for the above projects was secondary and high school students. Further, as our mobilized lessons were designed to cover the existing curriculum, we had to make a balance between serving the existing curriculum objectives and guided inquiry to scaffold student inquiry activities. Our curriculum activities were usually short in duration and enabled the learners to engage in a wider range of light-weight explorations rather than more protracted inquiries for a specific science question such as 'how can we produce healthier milk?' and 'how to design a climate-friendly house?'

While the PI project uses different technologies for different purposes (sensors, cameras, personal desktops and Ultra-Mobile PCs), we are interested in studying the sustained use of truly portable device in the form of a smartphone computer. Other differences relate to the context of our research. We are interested in exploring students taking the responsibilities and ownership of their learning by making the smartphone their personal learning device with anytime and anywhere access. Our goal is to transform school routine teaching and learning practices; in this case, we mobilize 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 (Zhang *et al*. forthcoming). The design, implementation, and evaluation were done concurrently so that we were able to improve our curriculum design and implementation in a timely manner. Furthermore, ours is a longitudinal study of a class having mobilized lessons over a period of 2 years.

The 'mobilized' primary science curriculum

We design our mobilized curriculum to be student centred, inquiry based and collaborative in nature (Zhang *et al*. forthcoming). With the use of the smartphone as a learning hub to integrate formal and informal learning activities, each student creates and maintains a broad range of documents (artefacts) associated with each curriculum unit, e.g. concept maps, text documents, photos and animations. The student's work is stored on the smartphone, which is backed up onto the GoManage server using the cellular network for Internet connectivity. In the curriculum design, we have applied the following guidelines with consideration of foregrounding an inquiry science approach and the affordances of the mobile technologies (Zhang *et al*. forthcoming):

- Design student-centred, inquiry-based learning activities. We model the inquiry processes and foster students' self-directed learning by initial teacher's facilitation of their inquiry-based learning.
- Exploit the affordances of mobile technologies. Tapping on the mobility that is afforded, usage of the mobile technologies is woven into the fabric of the learning activities, thus constituting an essential, integral component in the teaching and learning process. As the students are doing their science experiments, they can use a variety of tools available on the handhelds to support their learning. For example, they can list ideas and connect them using a concept map through the use of Picomap (Dallas, TX, USA). They may use the camera to capture examples of a science concept in their everyday life to connect what they learn in class.
- Assess student learning formatively. The teacher, students, and researchers had access to student artefacts during and after classes for timely assessment and adjustment of teaching and learning.
- Facilitate collaborative interactions. Mediated by mobile technology, students share their work in progress, resources, artefacts, and findings that they got from their Internet searches and cooperate together on their learning activities. Students can collaboratively compare and contrast information on their individual hand devices.
- Make use of community support and resources. Students make field trips to the local zoo and the science

© 2010 Blackwell Publishing Ltd

centre, and investigate science phenomena for meaningful learning.
- Support teacher development to be good curriculum developers and facilitators. Many regular meetings between teachers and researchers are held to co-design curriculum materials for the professional development of teachers and for researchers and teachers to share observations of classroom enactment of mobilized lessons.

Mobilizing the curriculum requires a holistic view of how the learning activities are organized via technology so that student learning is situated in authentic contexts to understand how the connections and coherence across various concepts. For example, in a visit to a probiotic drink factory, students learned about the presence of good bacteria in a drink commonly known to them and how the bacteria travels through their digestive system. We provide them an authentic context where we can connect their everyday experiences to science concepts. In this example, the concepts are bacteria in a living micro-organism and how the digestive system functions in a human body. Instead of learning the concepts in the abstract and in isolation, they learned about how the two concepts are connected such as how bacteria affect the digestive system. They might also relate this to their experiences of stomach disorders when they eat spoilt food.

The MLE provides the infrastructure to develop a project with driving questions, activities and learning resources. A project is a container of related and interdependent learning tasks. Each task is an instantiation of how the affordances of mobile computing enable personalized learning from four facets: (1) allowing multiple entry points and learning pathways; (2) supporting multi-modality; (3) enabling student improvisation in situ; and (4) supporting the sharing and creation of student artefacts on the move (Looi *et al*. 2009). Students can pursue their inquiry in a personalized way, without having to do the tasks in a strict sequential order. A good curriculum design will harness these affordances to transform a science curriculum into a mobilized one that makes science learning motivating, engaging and holistic.

A mobilized lesson design on body systems

The primary 3 science curriculum in Singapore comprises the two big themes of Diversity and Systems. Figure 1 shows a diagram of the various units in these two themes with linkages with planned home and informal activities as well as class field trips to the zoo, the horticulture park, and the priobiotic drink factory. Appendix I shows the learning objectives of these units.

In the following we describe the lesson design of topic on body systems. The goal for this series of lessons is to help students attain the learning objectives for the body systems through hands-on, cooperative and self-directed activities. These activities were done individually, with classmates and with parents. The activities were conducted not only in class but also in the students' homes. This extended the classroom hours for learning the body systems beyond the limited 4.5-h class time to over 3 weeks. The designed activities were packaged into GoKnow's MLE MyProjects, which could be accessed by the students on their smartphones

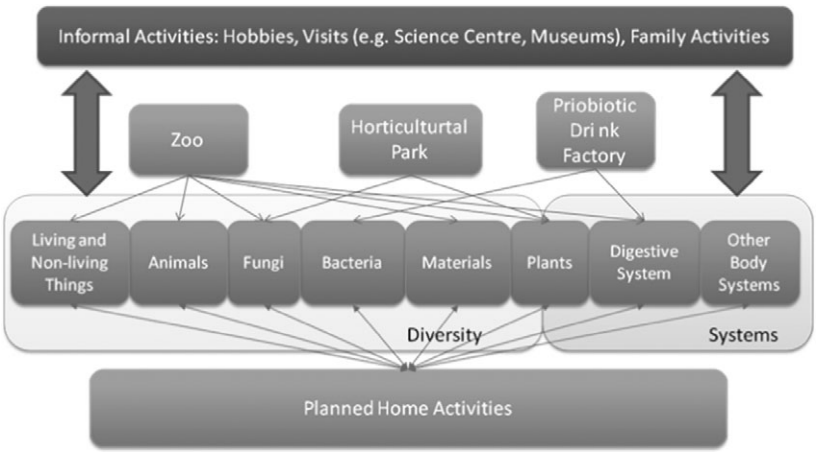


Fig 1 Mobilised curriculum for primary 3 science.

© 2010 Blackwell Publishing Ltd

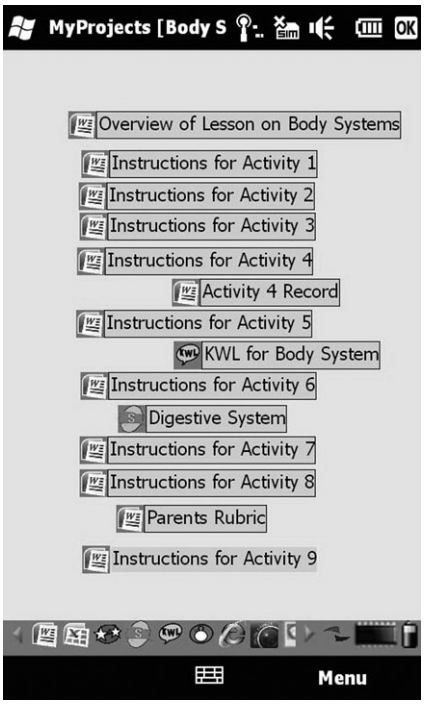


Fig 2 Screenshot of body systems lessons designed for the MLE.

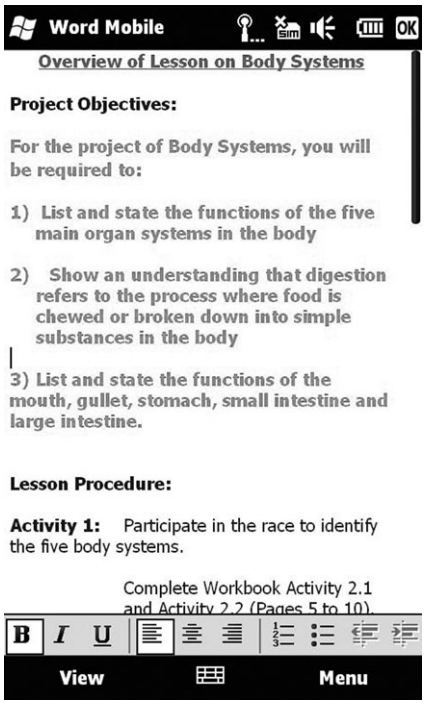


Fig 3 Overview of a body systems lesson on the MLE seen by the students.

as shown in Fig 2. A lesson overview shown in Fig 3 shows students the objectives of the lesson and what is expected from them in learning about the body system.

The students started the inquiry learning by playing a cooperative game to identify the parts and functions of five body systems. They helped one another to identify the parts correctly, and the teacher played the role of a critic to ensure that the students have identified the correct body parts and systems. After the game, the teacher recapped what the students had learnt from one another and reinforced their knowledge of the parts and functions of each body system.

Each student was then tasked to conduct an experiment at home with the help of his or her family members. Using the smartphone, the student video-recorded the experiment and used it to discuss with their classmates and teacher during the discussion in class. From this activity, the students learned that digestion starts from the mouth and how the mouth helps in the digestion process.

After that discussion, the students were required to do online research using their smartphones on digestive systems and to share their findings with their classmates. At the same time, the students were tasked to update their own KWL (what do I already *K*now? what do I *W*ant to know? What have I *L*earned?). This helped the teacher to identify learning gains and gaps in the conceptions of the students. The teacher addressed these findings during class time to help students clarify their alternate conceptions and at the same time learn from their friends. The students then created Sketchy (Dallas, TX, USA) animations of digestive processes to illustrate their understanding and used a rubric to help them assess the quality of their work. Before the teacher provided comments to their work, the students evaluated one another's work based on the same rubric. The teacher also shared these artefacts created by the students and at the same time offered suggestions to improve on the illustrations and the scientific representations in the students' work. Students were tasked to improve their work before re-submission.

The lessons culminated in an unusual teach-your-parent activity. The students were tasked to ask the parents what they know about the digestive system and to identify gaps in their parents' knowledge. They had to teach the parents what they thought the parents did not know and to interview their parents again to check their understanding. All the parent–child interactions were video- or voice-recorded using the child's HTC phone.

© 2010 Blackwell Publishing Ltd

Each student shared the audio or video recording of his or her parent–child interactions with a partner, and together they discussed and reflected on their own understanding of the digestive system.

In the co-design of the mobilized curriculum such as for the body systems unit, the researchers worked closely with the teacher to study the national science syllabus, the current textbooks, workbooks and related materials used, and the affordances of the mobile technologies to define the learning objectives. While the student activities were designed primarily for enactment in the classroom, we expect that student learning might continue in informal settings such as the home. In the designed lesson, they had to internalize their understanding to teach others what they know about the body system. Our strategy is to provide certain 'structures' to allow students to learn the skills and foster habits of minds so that they might transfer what they have learned to plan for their own self-directed learning. For example, if they learn how to use KWL and inquiry skills such as asking questions, designing investigations, collecting and analysing data, and making conclusions, they might plan their own self-directed and inquiry-based learning with topics that are not taught in class.

Research design

We adopted a design-research approach in our school-based work as we sought to address complex problems in real classroom contexts in collaboration with practitioners, and to integrate design principles with technological affordances to render plausible solutions. Our goal was to conduct rigorous and reflective inquiry to test and refine innovative learning environments as well as to refine new learning-design principles (Brown 1992; Collins 1992). In early cycles of the intervention, as enacted in the classroom implementation described here, we have focused very much on co-design of the mobilized curriculum, enactment of it into holistic lesson plans, teacher professional development, supporting classroom management and fixing technical problems that impede the smooth running of the technology.

There were nine classes in primary grade 3 in the school, three of which (Class A, B and C) are high-ability classes and six (Class D, E, F, G, H, I) are mixed-ability classes. Each class had about 40 students. The average age of the students across all the classes was 9 years old. The classification of ability in the Singapore context is based on the general examination scores of students at the end of their primary grade 2 year, and the assignment of students to their corresponding ability classes is random. We randomly chose one mixed-ability class (3E) for mobilized science curriculum intervention. The other classes were classes taught in the traditional way.

We have collected students' general science examination scores before and after the mobilized science curriculum activities, across all the nine primary grade 3 classes in the school. The general science examination papers comprised 30 multiple-choice questions and 14 open-ended questions, and the duration of the exam is 1 h and 45 min. All the nine classes took the same examination at the same time. Appendix II shows a sampling of some of the question items in the examination paper which are related to the topic of body systems.

Before and after the intervention, the students in the intervention class 3E filled in a questionnaire survey which comprised questions including the usage of mobile devices in and after class, and their perceptions and attitudes towards the mobilized lessons and the technology. To control the observe-expectancy effect, the students were told to be honest when answering the question. They were told that their answers would not be revealed to their teachers, nor would they be related to their exam results.

The research team started observations of the class at the beginning of the school calendar year prior to the introduction of mobile devices in class. The weekly observations were made to help researchers understand better about the class and the teacher before using the mobile devices for lessons. A science practice test was given to the students in all the mixed-ability classes just before the introduction of the mobilized lessons. The structure of this test was modelled after the science examination paper and was devised for this study. The results of this test served as the covariate in our analysis of covariance (ANCOVA) when comparing the students' final science examination results across classes.

After the introduction of the mobile devices, observations of the classroom continued with more lessons observed per week. In addition, we recorded several lessons involving the use of the mobile devices on video. When the lessons were recorded, one video camera was set in the back of the classroom. Two researchers observed each mobilized lesson and took

© 2010 Blackwell Publishing Ltd

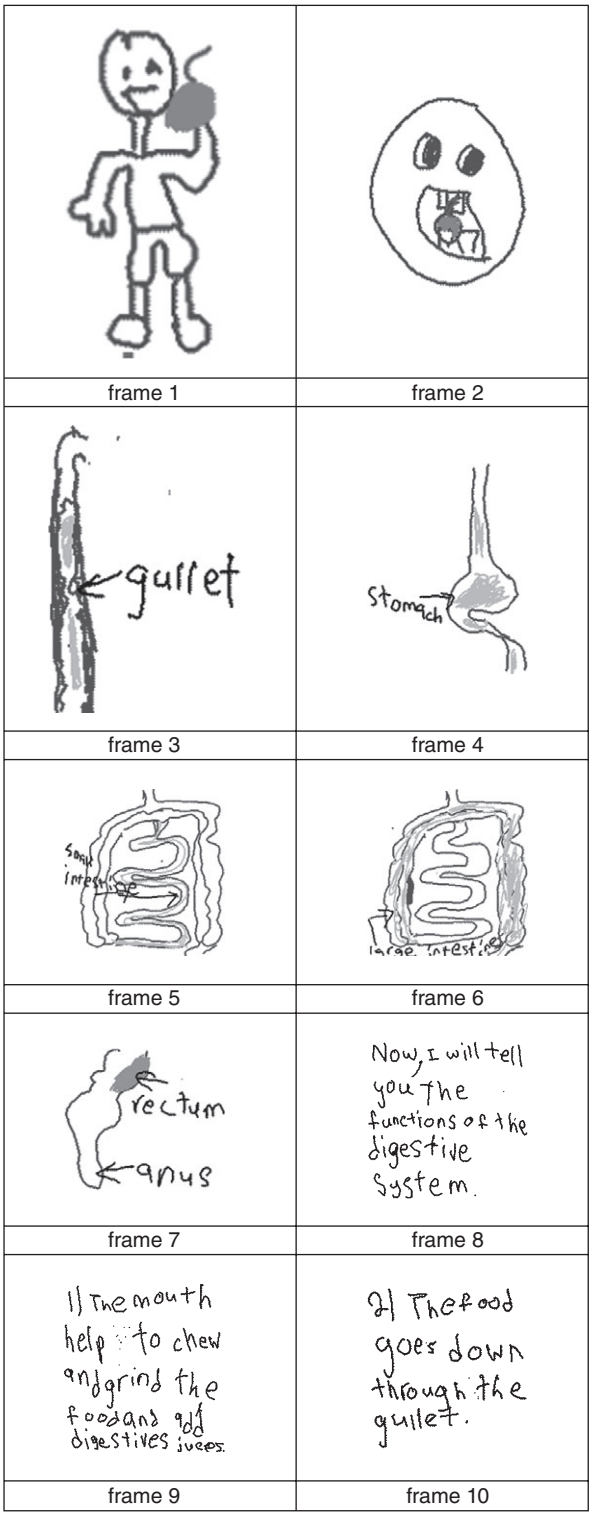
down detailed field observation notes. Occasionally we would look through the classroom video after the lesson to review the possibility of missing out any details from the actual 'live' observation of the class lesson. Artefacts created by the students during the lessons were collected and archived. The artefacts comprised of the students' Sketchy animations, KWL, Mobile Word documents and pictures taken through the use of the mobile devices. We also recorded each weekly professional development session in which the teachers were involved in the lesson co-design with the researchers.

Findings

In this section, we will present some observations of the teacher's enactment of the transformed curriculum in the classroom and report on perceived student and teacher changes as plausible mechanisms which explain the learning effect. We will present our findings from the quantitative analysis of data which shows positive gains for the experimental class compared with the other classes, followed by a discussion of students' usage of HTC phone in and out of class and their attitudes towards mobile learning over the duration of the intervention.

Student changes

Through our observations of the enacted lessons and our analysis of student-created artefacts using their mobile devices, we detect a shift in the classroom behaviour after the introduction of the mobile devices. The class comprised 39 students. The students were more engaged and are able to conduct research by formulating questions, conducting online search, collecting data, and producing quality animations and concept maps, as well as other digital artefacts to reflect their understanding and negotiate meanings collectively. For example, the students drew an animation of their understanding of the body system using Sketchy. Frames 1–7 in Fig 4 show a sequence of animation frames drawn by a student to illustrate his understanding of the digestive system. He showed how an apple eaten by him was digested starting from the mouth and the sequence as the food moved through the different parts of the digestive system. After the animated illustration, he wrote to explain the function of each part of the digestive system shown as shown from frames 8–10.



frame 1 | frame 2 | frame 3 | frame 4 | frame 5 | frame 6 | frame 7 | frame 8 | frame 9 | frame 10

Fig 4 A sequence of animation frames drawn by a student to illustrate his understanding of the digestive system.

© 2010 Blackwell Publishing Ltd

Our interviews with the parents during the home visits informed us about how the students taught their parents about the digestive system in our designed home activity. The students were asked to teach their parents about the digestive system and the function of each part. One student Roy's father recounted that his son was able to teach him without reading off materials. Roy was also able to identify that his father did not introduce the stomach and the intestine when he interviewed his father after the teaching. Roy's knowledge of digestive system impressed his father. The latter said:

> I think he knows more than what I know. What I know is very basic. Some of the parts I describe wrongly. He is very specific. Those terms that he uses are new to me also. He said a lot of things . . . I try to understand but it is a bit difficult. I think he knows his stuff.

Classroom observations provided instances that indicated students doing some form of self-directed learning. For example, some of them conducted independent research online: they searched for videos relevant to classroom learning from YouTube. Questions raised by the students during class focused more on the content of the lesson as compared with before the implementation. For example, their questions used to focus on clarifying the instructions of the teachers. The changes in the nature of the questions could be attributed to 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 to formatively make use of the information. Student questions in *What I Want to Know* reflect deep thinking and are more relevant to what they were doing. Figures 5–7 show some of the questions a student Jeremy asked in his KWL. He shared with researchers that he likes using KWL to watch his own learning progress. Some students have explored new applications for learning purposes.

We consider the behaviour of students asking their own questions and their changed mindset about not being afraid of asking questions (that might be deemed as 'stupid' by their peers and their teacher) as very significant cultural changes. These are among the most significant indicators of pedagogical change towards a culture of collective knowledge construction in the classroom. Students tended to write down their own answers on the worksheets rather than copy the answers from the teacher's board. They were more confident of their own answers and would integrate their answers

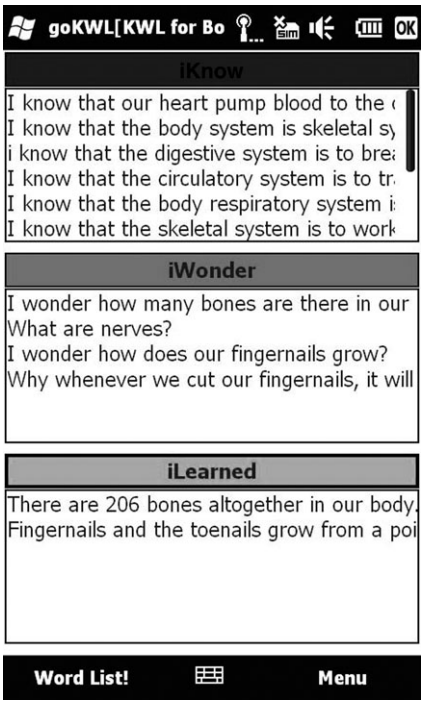


Fig 5 KWL-body systems.

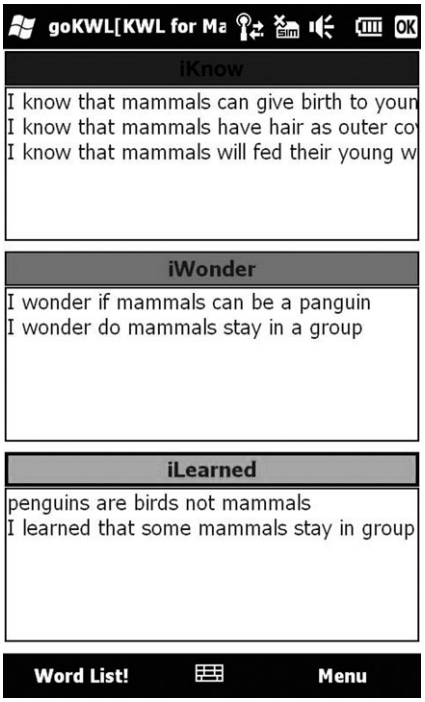


Fig 6 KWL-mammals.

© 2010 Blackwell Publishing Ltd

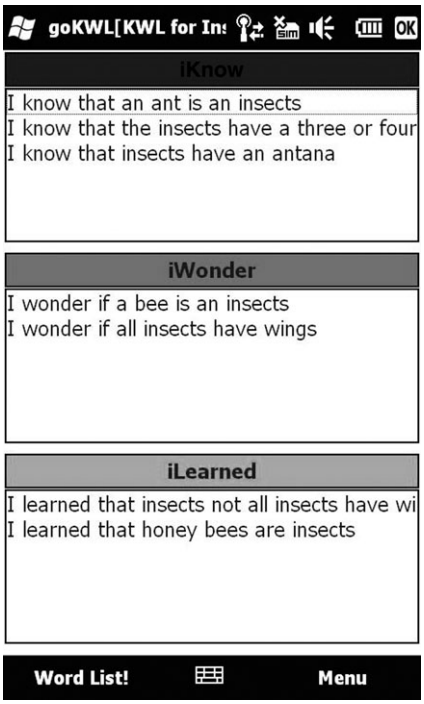


Fig 7 KWL-insects.

with the teacher's written answer. The students were more aware and curious of the surroundings around them.

We noted signs of self-discipline in the class when the students were carrying out tasks on their mobile devices even without little supervision from the teacher. During the class when the batteries of some of the students' devices run low, they organized themselves orderly in deciding who should charge the devices. Although there were a limited number of chargers, the students waited patiently for their turn. As the devices were being charged, the students would sit or stand besides the chargers working on their task on the mobile devices as shown in Fig 8. The use of the mobile devices fostered collaboration among students. Some students paired up to work on their assignments during class time. The mobile devices mediated the face-to-face interaction as the students worked on their individual assignment on their personal smartphone and interdependently with their friend as shown in Fig 9. They fostered social interaction over the sharing of videos, the sharing of answers they found on the Internet and towards making group decisions, using information from the Internet to resolve conflicting individual ideas and integrate their ideas, teaching one another new software they have learned, and helping one another to solve technical problems.



Fig 8 Students work on their task while charging the smartphones.



Fig 9 Students working together mediated by the use of the smartphones.

Teacher changes

The teacher, Jean, taught English, science and mathematics to the class. She has about 3 years of teaching experience. In interviews with her, before the intervention of the mobilized lessons, she had expressed her lack of confidence in teaching science content knowledge, and she did not think that she was a good science teacher then. After the intervention, she said that she felt more competent as a teacher and was more prepared to teach science.

© 2010 Blackwell Publishing Ltd



Fig 10 Teacher discusses with the students in the group.



Fig 11 Teacher reviews the students' work on their mobile devices in facilitating their learning.

From the observations of the class before the introduction of the mobilized lessons and our interviews with her, the teacher felt pressurized to cover the essential learning points through a teacher-centred approach (teach to textbook). She was task oriented and aimed to finish the predefined drill-and-practice activities in the conventional curriculum in the stipulated time. Since the introduction of the mobilize lessons and the use of the handhelds in her classroom, she felt that she did not need to teach according to the textbook. She said that the teaching of science was not confined to the textbooks with which she previously relied heavily on. With the mobilized lessons, we detected a transition from didactic teaching to student-centred learning. She was inclined to give students more time to construct their own understanding rather than feed them with information. She tended to give more time to the students to answer the questions before providing the answers. With more time to observe students learning with mobile devices, she learned to identify student learning difficulties when she facilitates student learning (see Figs 10 and 11). The designed MLE lessons did not necessitate the teacher having to talk and take the initiative all the time. When implementing the MLE lessons, she instructed when the situation called for it, enabling her to spend more time facilitating the learning processes rather than providing answers. As a result of adopting the mobilized curriculum in the class, the teacher shared with the researchers that she has had more time to reflect on her lessons even during class. She said that she could think on her feet and improvise on the lessons in real time.

In an interview with researchers, the teacher recalled her experience since she joined the project and worked with the curriculum development task force, and 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:

> I gained some Science content knowledge. I thought Science is boring and difficult subject to master. through this PD sessions we start discussing topics like actually we can do this with the pupils and how can we teach the students this content that they could actually learn it. through that process though I did not go through NIE training. I thought it might more fruitful than in going through the NIE training

> When I teach Science I usually follow the textbook. I did realize I can teach this chapter first before I teach that chapter. it is until this PD sessions that I can this before I teach that. that is something new that I learned

Her further elaboration highlighted some fundamental dispositional and behavioural changes in herself:

> I do not have much confidence in teaching Science . . . no confidence at all. because myself I am not trained in Science. that part really deters me a bit. and I never see myself as an upper primary science teacher at all. but now the perception changes in me. now I feel more confident

> I did not realise that they can have misconception . . . When I teach I give you all the content and children do not have the misconceptions.it is only last year when we have the sessions then I realize it might the mode also.in the past I did not look at. before and I think of what are the misconceptions the kids might have. It never strike my mind to address the misconceptions.it is only until we have the PD that we look into what misconceptions the kids might have and address it

© 2010 Blackwell Publishing Ltd

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 (Zhang *et al.* 2010). The co-design process allowed researchers to understand tensions between using mobile technologies in science learning in the classroom and the existing concerns of the teacher, such as assessment, in order to develop feasible and evolutionary strategies towards transforming the classroom science pedagogy.

Positive science learning gains of the experimental class

Performance in assessments is always a concern of teachers, students, parents, principals and other stakeholders. We did a comparison of the students' general science final examination scores after the mobilized lessons. Among all the classes, 3E was the only one with the mobilized curriculum intervention. To examine the impact of the mobilized curriculum on students' learning, we compared the P3 year-end exam scores across the six mixed-ability classes.

To remove the obscuring effects of pre-existing individual science score differences, we conducted one-way ANCOVA to examine the P3 year-end science exam score (dependent variable) differences across six classes (independent variable) with the science scores from the practice test (before the first mobilized lesson) as the covariate. The question structure of the testing in the previous semester was similar to that of P3 year-end exam. The introduction of test scores from the previous semester as the covariate is to ensure that the six mixed classes were starting out approximately equal before the introduction of the mobilized curriculum. The assumptions of ANCOVA are met: (1) the independent variable (mobilized curriculum implementation) and the covariate (exam scores in previous semester) were independent; (2) the dependent variable (science exam scores of current semester which was after the mobilized curriculum implementation) was linearly related to the covariate (exam scores in previous semester); and (3) the slope for the regression line between the dependent variable and the covariates(s) was the same for each group. In the ANCOVA, the P3 year-end exam scores will be adjusted after controlling for the testing score from the previous semester (see Table 1).

Table 1. ANCOVA on year-end science exam scores across six 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
3D	39	75.49	7.786	71.50
3E	39	76.67	8.588	74.11
3F	41	71.63	8.952	68.22
3G	36	41.36	16.507	48.90
3H	40	55.95	12.704	59.31
3I	39	72.13	7.706	71.87
Total	351	72.25	16.528	71.50

The ANCOVA results show that there is significant difference on year-end science exam scores among the six mixed-ability classes after controlling the exam score before the introduction of mobilized lessons constant [$F(5345) = 31.619, P < 0.01$]. The class difference explains 41.1% of the variance in the year-end exam scores. The intervention class 3E has 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.

Attitudes towards the use of mobile devices for learning

Pre- and post-surveys of attitudes towards the use of mobile devices for learning were administered to the students at the beginning and after the completion of the mobilized lessons. The majority of the students felt the HTC smartphone was easy to use, easy to hold and light enough to carry. Screen size and keyboard size was a concern for some teachers. However, about 2/3 of the students did not think the size of the screen and the keyboard is too small for their schoolwork (see Table 2).

The majority of students held the positive view towards the HTC phone for learning. Around 80% of the students thought that the HTC phone helped their learning in and out of class. Sixty-two per cent of students thought that by using the HTC phone, they understood the science concepts learned better and they understood better how things they learn in class were connected to their daily life.

The school had a long tradition of using Pocket PCs for field trips before our mobilized lesson intervention.

© 2010 Blackwell Publishing Ltd

Table 2. Students' attitude towards HTC phone for learning.

	Agree/strongly agree (%)	Neutral (%)	Disagree/strongly disagree (%)
It is easy to use.	71.8	20.5	7.7
It is easy to hold.	66.7	33.3	0
It is light enough for me to carry.	74.4	17.9	7.7
The size of the screen on the HTC smartphone is too small to do my school work.	25.6	10.3	64.1
The size of the keyboard on the HTC smartphone is too small to do my school work.	17.9	15.4	66.7
It distracts me from doing my school work.	7.7	25.6	66.7
It helps me learn my class subjects.	84.6	12.8	2.6
It helps me learn things outside of school.	78.9	18.4	2.6
I understand the science concepts learned in class better.	61.5	35.9	2.6
I understand better how things I learn in class are connected to my daily life	61.5	33.3	5.1

The students of class 3E had used Pocket PCs for their learning a few times when they were in primary grades 1 and 2. In both pre- and post-intervention surveys, we asked students the same set of questions about the role of mobile device for their learning. Paired-sample *t*-tests were conducted to compare the mean scores of the attitudes towards mobile devices for learning between the pre- and post-surveys. As shown in Table 3, there is a significant improvement in students' attitudes towards mobile devices for learning from the pre- to the post-survey. The response scale is a Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neutral, 4 = Disagree and 5 = Strongly Disagree. Thus, the lower the score, the more positive the student's attitude towards mobile devices for learning is. The scores in the range 1–2 means that the students' average attitudes were between Agree (2) to Strongly Agree (1). After the mobilized curriculum intervention, the students had more positive attitudes towards the use of mobile devices for learning in [$t(38) = -2.765$, $P < 0.01$] and out of the classroom [$t(38) = -2.321$, $P < 0.05$].

After the mobilized curriculum intervention, the students liked the learning activities using computers and gadgets more than before [$t(38) = -2.016$, $P < 0.05$]. They perceived themselves as learning more when working in a group than working alone [$t(38) = -2.634$, $P < 0.05$].

Discussion and conclusion

In seeking to put together a coherent classroom programme that can be sustainable, our work faces the real challenges of introducing an intervention in the real classroom. Our unique research context is that we worked with a school with nine classes in the cohort of primary grade 3 taking the science subject. The experimental class has to follow the same class schedule and assessment schemes as the rest of the classes. Our

Table 3. Paired sample *t*-test comparing the students' attitudes towards mobile devices for learning.

		Mean	*N*	SD	t
The mobile devices help me learn my class subjects.	Pre survey	1.46	39	0.643	–2.765**
	Post survey	1.82	39	0.451	
The mobile devices help me learn things outside of school.	Pre survey	1.42	38	0.683	–2.321*
	Post survey	1.76	38	0.490	
I like the learning activities using computers and gadgets.	Pre survey	1.05	39	0.223	–2.016*
	Post survey	1.23	39	0.536	
I learn more when I work in a group than alone.	Pre survey	1.37	38	0.633	–2.634*
	Post survey	1.68	38	0.662	

*$P < 0.05$; **$P < 0.01$

© 2010 Blackwell Publishing Ltd

research work is situated in such a trajectory towards making an impact on practice. In our intensive school-based work, we design and implement 1 year's worth of mobilized lessons in science, which will expand to cover more subjects in the subsequent years. In the SCY project, five inquiry missions are designed, and each inquiry learning mission or scenario takes at least two to six lessons of learning time (de Jong *et al*. 2009). As they are designed for the purposes of research, they are likely to be authentic activities whereas our mobilized lessons are designed to cover the curriculum but with an inquiry perspective.

We have described our empirical study in exploring the learning effectiveness of a science curriculum transformed for delivery and for learning on mobile technologies. Our analysis of the science examination scores of the mixed-ability classes shows that the students receiving instruction using the mobilized curriculum outperformed those of the classes taught the traditional way. We feel that this result is a very worthwhile contribution to the field, as much research work on mobile learning focus only on units of at most a few weeks' duration, or they are add-on activities to some existing curriculum, or they are extra-curricular activities.

The use of the mobilized technologies provides many leverage points for the researchers and teachers to co-design a new curriculum that focuses on inquiry learning. The designers have to spend a lot more time to design the mobilized curriculum. Once designed, the curriculum can be enacted by science teachers, and it is important for the teachers to understand the design principles behind a mobilized curriculum for inquiry learning and how to implement in the way to harness the best learning outcomes for students. We see a shift in the teacher's attitudes and behaviours towards science teaching, from a style that sees her preoccupied with just covering the curriculum to one that allows her to watch over and facilitate students' work on the inquiry activities on their handhelds.

With the mobilized lessons, we observe students engaging in science learning in personal and engaged ways. They demonstrated their understanding of science phenomenon in multimodal ways and did self-directed learning by doing online search and exploration on questions related to the curriculum topics. They engaged in instructional activities that involve their parents, as in our mobilized lesson for the body systems. This lies in contrast to the more 'traditional' way of learning, in which students learned science from the didactic instruction of the teacher or from the textbook.

In considering the role of technology in mobilized learning, we have observations of how the technology is fostering thinking in the students: they drew and animated on the Sketchy to demonstrate their understanding; they listed ideas and connected them on PicoMap; they constructed comparison of concepts on Word; they searched for terms and ideas on the Internet; they observed videos on YouTube; they did research on their own and synthesized the ideas they found; they observed the world around them and record them by taking pictures; and they had a tool to capture those learning moments that interest them. It is true that they could do this on a plethora of devices: desktop PCs, Ultra-Mobile PCs and cellphone computers, but it is the one device that they always have access to (the immediacy) as a learning hub (continuum and consistency) and that provides the mobility for them to learn outside of the classroom, on the move and across contexts, and thus really enabled students to take both responsibilities and ownership to motivate them. We have done intensive teacher professional development, but without the above affordances of mobile technology and the educational software that runs on them, it would be less possible to design and enact such an innovative curriculum.

In summary, this work provides a concrete example of a science reform effort in which the conventional science curriculum is transformed into a mobilized curriculum over the sustained period of a year. Positive outcomes are attained in terms of science assessment learning gains, increased students' engagement in science learning, increased teacher's agency in delivering the science curriculum in the class, and positive attitudes of the students towards the use of mobile devices for learning.

Acknowledgements

This paper is based on work supported by the Learning Sciences Lab and a grant from the National Research Foundation, Singapore (Grant #: NRF2007IDM-IDM005-021). We wish to thank GoKnow Learning, Inc. (Ann Arbor, MI) for providing a license to use the GoKnow Mobile Learning Environment software in Singapore. We are grateful to Nan Chiau Primary School for collaborating with us on this research.

© 2010 Blackwell Publishing Ltd

Appendix I

The Mobilized Curriculum with Learning Objectives and Linkages to Out-of-School Learning

Duration	Topic	Learning Objectives	Extension from Other Topics/ Field Trips/ Personal Experiences
3 Weeks	Living and Non-living Things	1. Describe the characteristics of living things. – need water, food and air to survive – grow, respond and reproduce 2. Observe a variety of living and non-living things and infer differences between them. 3. Classify living things and non-living things into broad groups based on similarities and differences of common observable characteristics.	1. Identify plants and animals from the artifacts collected from the zoo trip 2. Classify the artifacts of the living and non living things collected from the zoo trip. 3. List ways of classification in daily lives and how such practices help them 4. Collect artifacts of the plants and animals in the school and other surrounding environment
2 Weeks	Plants	1. Recognise that plants are living things 2. Recognise that there is a variety of plants in our surroundings 3. Classify plants into broad groups based on similarities and differences	
3 Weeks	Classifying Animals	1. Classify animals into broad groups based on similarities and differences 2. Identify and describe the types of outer coverings that animals have 3. State and explain how animals reproduce	1. Recall that animals are living things 2. Describe and compare the different sizes, shapes and colours of animals observed during the zoo trip 3. Identify the similarities and differences of artifacts animals use in the previous topic 4. Reclassify the animals that were created in the previous animals
1 Week	Bacteria	1. Recall the characteristics of living things – need water, food and air to survive – grow, respond and reproduce 2. Recognise that bacteria are Living Things which need air, water and food to stay alive 3. State that Bacteria are Micro-organisms 4. Describe how some Bacteria can be use and how others can be harmful	1. Recall what they have learnt from Priobiotic Drink trip 2. State the similarities and differences between animals and bacteria.
3 Weeks	Materials	1. List some materials and relate their properties to their uses, e.g. wood, metal, rubber, plastics, fabric, ceramic, glass. 2. Relate the properties of materials to their uses 3. State the different properties of materials 4. State the ways to test the properties of material 5. Identify the appropriate materials to use for different objects based on what the objects are used for.	1. State how materials are used in the school and home environment 2. Show how materials can be tested for their properties 3. Collect evidence to show how the properties of the materials affect the way they are used 4. Classify materials based on their properties and uses
1 Week	What is a System?	1. Describe what a system is 2. Recognise that systems can also be found in living things, such as plants and animals 3. Explain how a plant can be considered a system	1. Show how a system can be taken apart and analysed (ball point pen, correction tape with gear system) 2. Give examples of how a failed system can affect their daily lives.

© 2010 Blackwell Publishing Ltd

Appendix I: *Continued*

Duration	Topic	Learning Objectives	Extension from Other Topics/ Field Trips/ Personal Experiences
3 Weeks	Plant and Plant Parts	1. Identify and explain what is a system 2. Identify and state the functions of different parts of plants e.g. leaf, stem, root. 3. Compare different parts of plants e.g. leaf, stem, root according to shapes, sizes, colour and texture. 4. State and label the transport system of the stem.	1. Provide evidences of a failed plant system and explain the consequences
1 Week	Fungi	1. Recall the characteristics of living things – need water, food and air to survive – grow, respond and reproduce 2. State the characteristics of fungi 3. Recognise fungi and provide examples (e.g. mushroom, yeast) 4. Recognise that fungi are Living Things which need air, water and food to stay alive	1. Provide examples of fungi in their daily lives (e.g Fungi that are edible, fungi that grow on living and non-living things)
4 Weeks	Body Systems	1. List the parts of the five main organ systems in the body and explain how they work as a system 2. List and state the functions of the five main organ systems in the body 3. Show an understanding that digestion refers to the process where food is chewed or broken down into simple substances in the body 4. List and state the functions of the mouth, gullet, stomach, small intestine and large intestine.	1. Teach peers and parents what they know about the digestive system 2. Assess peers', peers' parents and own parents knowledge on digestive system

Appendix II

Examples of questions (related to the topic of Body System) from the science examination paper

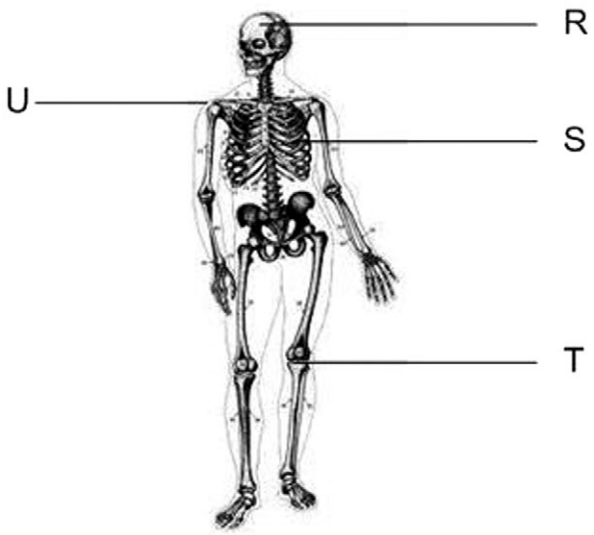
1. The following table shows the functions of four human systems. Which body system has its function incorrectly stated?

	Body System	Function
1	Digestive	Breaks down food into simpler substance
2	Muscular	Helps different parts of the body move
3	Respiratory	Takes oxygen away from the body
4	Skeletal	Gives shape to the body

2. Which of the following parts of our body need oxygen?
   (a) Heart and lungs only
   (b) Brain, heart and lungs only
   (c) Stomach, small intestines and large intestine only
   (d) All parts of the body

© 2010 Blackwell Publishing Ltd

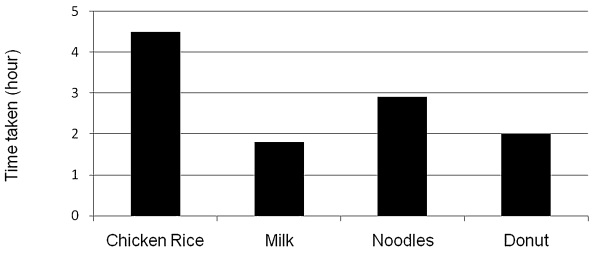
3. The diagram below shows the human skeleton.



Which one of the following statements is true?

(a) Part R helps us to move our head
(b) Part S protects our heart and lungs
(c) Part T allows the knee to move in more than one direction
(d) Part U allows the arm to move in one direction only

4. The graph below shows the time taken for the body to digest four different types of food.



Which food was the most easily digested?

(a) Milk
(b) Donut
(c) Noodle
(d) Chicken Rice

5.

(a) The table below describes the movement of food through the digestive system. Complete the table by writing the numbers 1 to 6 in the boxes to show the correct sequence in which food moves through the digestive system.

© 2010 Blackwell Publishing Ltd

Description	Sequence
The digestive juices in the stomach break down the food.	
The food travels down the gullet into the stomach.	
Water is removed from the food. Undigested food is passed out through the anus.	
Undigested food passes into the large intestine.	
Digestion is completed in the small intestine. The digested food passes into the blood vessels.	
I bite into my sandwich. My teeth chew and grind the food.	

(b) Name two parts of the digestive system which do not have digestive juices.

(i) _____

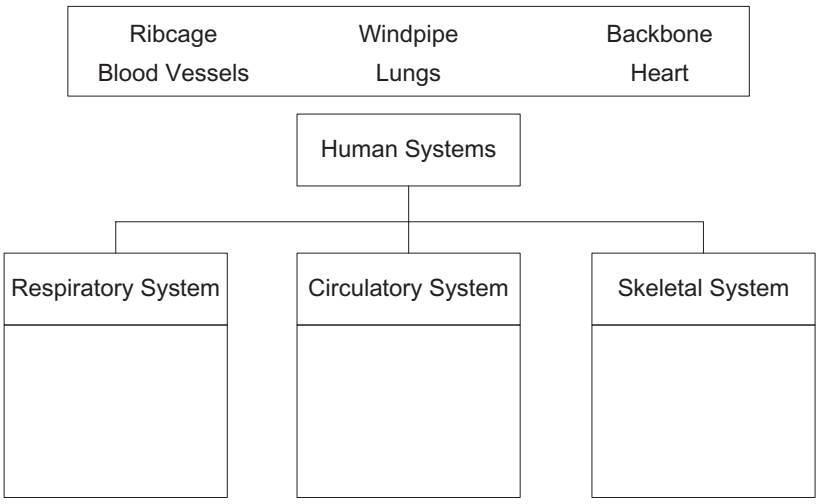
(ii) _____

(c) In which part of the digestive system does most of the digestion of food take place?

_____

6.

(a) Complete the classification chart below with the words given in the box.



(b) Which system is also known as the transport system of the human body?

_____

References

Brown A.L. (1992) Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences* **2**, 141–178.

Chan T.-W., Roschelle J., Hsi S., Kinshuk K., Sharples M., Brown T., Patton C., Cherniavsky J., Pea R., Norris C., Soloway E., Balacheff N., Scardamalia M., Dillenbourg P., Looi C.-K. & Milrad M. (2006) One-to-one technology-enhanced learning: an opportunity for global research collaboration. *Research and Practice in Technology Enhanced Learning* **1**, 3–29.

Chen W., Tan N., Looi C.K., Zhang B.H. & Seow P. (2008) Handheld computers as cognitive tools: technology-enabled environmental learning. *Research*

© 2010 Blackwell Publishing Ltd

and Practice in Technology Enhanced Learning **3**, 231–252.

Collins A. (1992) Towards a design science of education. In *New Directions in Educational Technology* (eds E. Scanlon & T. O'Shea), pp. 15–22. Springer, Berlin.

Dow P. (2000) *Why Inquiry? A Historical and Philosophical Commentary. Inquiry Thoughts, Views, and Strategies for the K-5 Classroom*. Available at: http://www.nsf.gov/pubs/2000/nsf99148/htmstart.htm (last accessed 18 July 2010).

de Jong T., van Joolingen W.R., Weinberger A. & The SCY Team (2009) Learning by design. An example from the SCY-project. *Proceedings of the CSCL 2009 conference*, Rhodes, Greece, June 8–13, 2009.

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

Looi C.-K., Wong L.-H., So H.-J., Seow P., Toh Y., Chen W., Norris C. & Soloway E. (2009) Anatomy of a mobilized lesson: learning my way. *Computers & Education* **53**, 1120–1132.

Maldonado H. & Pea R.D. (2010) LET'S GO! To the creek: co-design of water quality inquiry using mobile science collaboratories. *Proceedings of the Sixth International IEEE Conference on Wireless, Mobile and Ubiquitous Technologies in Education (WMUTE 2010)*, pp. 81–87. IEEE.

Norris C. & Soloway E. (2008) *Getting Mobile Handhelds Help Bring K-12 Classrooms Into the 21st Century*, District Administration Magazine, Professional Media Group, LLC, CT. Available at: http://www.districtadministration.com/ (last accessed 20 October 2010).

Roschelle J., Patton C. & Tatar D. (2007) Designing networked handheld devices to enhance school learning. In *Advances in Computer*, Vol. 70 (ed. M. Zelkowitz), pp. 1–60.

Scanlon E., Littleton K., Gaved M., Kerawalla L., Mulholland P., Collins T., Conole G., Jones A., Clough G., Blake C. & Twiner A. (2009) Support for evidence-based inquiry learning: teachers, tools and phases of inquiry. *Proceedings of the 13th Biennial Conference of the European Association for Research on Learning and Instruction (EARLI)*, 25–29 August 2009, Amsterdam.

SCY (n.d.) *Science Created by You*. Available at: http://www.scy-net.eu/ (last accessed 19 July 2010).

Sharples M. (2009) *Personal Inquiry Supporting Inquiry Science Learning across Formal and Informal Settings, Presentation at Kings College London*. Available at: http://www.pi-project.ac.uk/publications/ (last accessed 27 July 2010).

Spikol D., Milrad M., Maldonado H. & Pea R. (2009) Integrating co-design practices into the development of mobile science collaboratories. In *Proceedings of the 9th IEEE International Conference on Advanced Learning Technologies (ICALT 2009)* (14–18 July). Riga, Latvia.

Squire K. & Klopfer E. (2007) Augmented reality simulation on handheld computers. *Journal of the Learning Sciences* **16**, 371–413.

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 & Education* **53**, 286–299.

Vogel B., Spikol D., Kurti A. & Milrad M. (2010) Integrating mobile, web and sensory technologies to support inquiry-based science learning. *Proceedings of the 6th IEEE WMUTE International Conference on Wireless, Mobile and Ubiquitous Technologies in Education WMUTE 2010*, Kaohsiung, Taiwan, April 12–16th, 2010.

Wichmann A., Hoppe U., Spikol D., Milrad M., Anastopoulou S., Sharples M., Pea R., Maldonado H. & de Jong T. (2010) Three perspectives on technology support in inquiry learning: personal inquiry, mobile collaboratories and emerging learning objects. *Proceedings of the 9th International Conference of the Learning Sciences*, 29 June–2 July 2010, Chicago, IL.

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

© 2010 Blackwell Publishing Ltd