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HANDHELD COMPUTERS AS COGNITIVE TOOLS: TECHNOLOGY-ENHANCED ENVIRONMENTAL LEARNING

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This design-based research uses handheld computers as cognitive tools to facilitate students' inquiry-based learning on environmental issues — 3Rs (*Reduce*, *Reuse* and *Recycle*) in a Singapore primary school. Using handheld computers throughout a field trip, 79 Primary grade 4 students investigated how wastes are produced and what impact 3Rs can have on protecting the environment. The handheld computers were used to support, guide, and extend student thinking process within and out of classroom. Pre- and post-tests were conducted to examine their awareness and knowledge on 3Rs. Pre and post-surveys were administrated to explore student attitudes and perceptions on the role of the handheld computers in learning. The research results indicated improvements in the students' understanding of the 3Rs and internalization of their understanding through application of the 3Rs concepts. In this study, it was not only the technology affordances but also the way the technologies were used in the context of the learning environment and the associated pedagogy that enabled the handheld computers to serve as cognitive tools.

Keywords: Cognitive tool; handheld computer; mobile learning; environmental education.

1. Introduction

As cutting-edge mobile technologies, handheld computers (e.g. Windows Mobile Pocket PCs, Windows Mobile Phones, Ultra Mobile PCs, etc) have great potential in learning and education. The use of handheld computers in schools is increasing and there have been studies investigating the effectiveness of handheld computers in student learning. Pownell and Bailey (2002) asserted that the constructivist nature of learning with handheld computers can transform teaching and learning. The portability and mobility of handheld computers allow students to no longer be bound to one location, but instead free them to work continually as their location changes. Handhelds can help data collection and analysis, and the high interactivity enabled by beaming makes collaboration and communication among students handy (Pownell & Bailey, 2002). In addition, handhelds are easy to use, require little training, and therefore allow students to concentrate on the learning rather than the technology itself. Many studies showed that handheld computers play a significant role in impacting teaching and learning (e.g., Greaves, 2000; Joyner, 2002; Vahey & Crawford, 2005; Tinker & Vahey, 2002).

Many standard built-in applications of handheld computers, such as Word™, Power Point™, Excel™, calculator, Internet Explorer™, and Media Player™, are very useful across many learning activities. Recent advancements in handheld computers have increased new possibilities and opportunities for educators to capitalize on the affordances of this cognitive tool. The more recent models incorporate the functions of computing power, personal information manager, telephony, wireless Internet connectivity, digital camera, and other features. The applications employed for learning can vary greatly according to the context and situations. These applications on handheld computers can become cognitive tools themselves when supporting the visualization of student knowledge construction processes, promoting cognitive and metacognitive thinking and fostering learning for understanding. Ideally, cognitive tools have the potential to amplify and augment mental functioning (Pea, 1985; Salomon, Perkins & Globerson, 1991).

Cognitive tools are generalizable computer tools that are intended to engage and facilitate cognitive processing (Kommers, Jonassen, & Mayes, 1992). Cognitive tools have played a crucial role in providing the means through which many constructivist leaning activities are enacted, enabling a wide array of affordances with which individuals access, manipulate and construct knowledge (Jonassen & Reeves, 1996). Lajoie and Derry (1993) expressed that cognitive tools could support learning by explicitly supporting or representing cognitive processes.

Although the use of handheld computers in learning is well documented, the use of handheld computers as cognitive tools is still not common. Using a computer as a "cognitive tool" supports the external construction of cognitive processes. Kozma defines cognitive tools as "devices that allow and encourage learners to manipulate their thinking and ideas" (Kozma, 1987, p. 21). By externalizing the cognitive processes, the tools seem to free "short term memory" for the accomplishment of learning related tasks (Kozma, 1987; Mayes, 1992). Jonassen uses a similar term, "mindtools," to refer to a series of computer software applications as cognitive tools (e.g. Jonassen, 1997, 2005). Mindtools are computer-based tools and learning environments that have been adapted or developed to enable learners to represent what they know (Jonassen, 2005). Handheld computers can function as intellectual partners that share the cognitive burden of carrying out tasks, such as calculating, storing, and retrieving information. In this study, we use handheld computers as cognitive tools to facilitate inquiry-based learning among primary school students in a field trip, on some environmental issues in Singapore, namely 3Rs (*Reduce*, *Reuse* and *Recycle*). We also examine the students' learning gains and their attitudes toward handhelds, which is a new perspective different from most existing studies with a focus on the design of learning activities using handhelds.

2. Curriculum and Participants

Environment issues were chosen as the curriculum of the learning activities. In Singapore, the growth in solid waste generation places considerable demands on waste management, disposal facilities and the environment, which may restrict the further development for Singapore as a city country with small landscape. The best way to address this issue is to reduce, reuse or recycle things that we throw away. Each is a way to reduce the amount of garbage dumped in landfills, to conserve non-renewable resources, and to protect the environment. Traditionally children are taught about the 3Rs through static displays, exhibitions, recycling activities and participation through environment clubs. The specific environmental education programs are not common at primary school level. This study proposes innovative pedagogies for primary school student to learn about conserving the environment through being equipped with handheld computers to engage in critical thinking skills, inquiry and problem solving.

About 480 students from six schools participated in the project, which spanned over two weeks. To understand the effectiveness of our design, we conducted a study on 79 primary grade-4 students from one of the participating schools to evaluate what they had learned about the 3Rs and how they had applied their understandings. Among the 79 students who were from 2 classes, 60% of the students were male and 40% were female, with an average age of 10. Students were divided into groups of four for most of the class activities. Each group had roughly one high achiever, one low achiever and two average students based on the results of their last science continual assessment.

3. Pedagogy Design

Our approach in designing the learning activities and learning environment is to support student learning through activities within a meaningful context in and out of classroom. Some of the activities are mediated through the use of technologies, such as handheld computers, wireless, and online technologies, which can be used as cognitive tools to enhance their learning.

The proposed pedagogy is what we called the Challenge Experiential approach (Figure 1). In order to provide an authentic context for learning (Brown, Collins, & Duguid, 1989), we start experiential learning cycle with a challenge phase. Students are given a scenario or an authentic problem to solve as a challenge. Using challenge as the beginning of the inquiry process, students learn by acquiring relevant information according their needs (Schwartz, Lin, Brophy, & Bransford, 1999). The pedagogical approach is also based on "experiential learning" where learning occurs through the process of experience, and knowledge is created "through a transformation of experience" (Kolb, 1984). When children use an experiential learning

Figure 1. A Challenge-Experiential cycle on the handheld computer.

model, where they would feel, reflect, think, and apply their knowledge by doing, they would become better learners (Fielding, 1994). This may lead to a modification of their prior knowledge and application of knowledge in practice. The challenge experiential learning model in this project is as follows:

Challenge: The teacher presents the background of the lesson and the challenge to the students with questions addressing the concepts to learn. Students are asked to record some of their prior knowledge through questions like what their predictions are or what they expect to see.

Experience: Students perform a set of activities in the context of the learning objectives. Examples of the activities are observing how plastic bags are given in the supermarket or interviewing the public on their awareness of the environment.

Reflecting: Students reflect on their experience. They share about what happened and what is important in their experience. This helps the students develop their logical reasoning, verbalize their thoughts and share their experience with others.

Planning: Students relate what they have experienced to their own lives and the real world by making an action plan to promote 3Rs ideas at home and their communities.

Applying: Students are asked how they would apply what they have learned to similar or different practical situations. This will help the students to contextualize their learning.

The pedagogy design consists of 5 activities (Figure 2). First, technical training was conducted to equip the participants the necessary skills to use the cognitive tools. The second stage is "challenge", where the teacher gave an introduction to the problem caused by the large amount of garbage and the students were given a challenge on "*What will happen to our environment if I do not practice the 3Rs? What can I do to reduce, reuse and recycle?*" The students made use of a KWL (What I know, What I want to know, & What I learned) chart to keep track of their learning on the topic of environment. The third stage is "experiencing" where the students were equipped with handheld computers to carry out three learning tasks at a supermarket with the goal of gathering evidence in determining whether Singaporeans are environmentally friendly. At the fourth stage, the students generated a report on handheld computers and uploaded it to a 3Rs online portal by clicking the "upload" button on the screen. The students thereafter viewed the work of other groups, provided feedback to their peers' work and posed additional questions to the environmental experts. Finally, each group of students made presentations

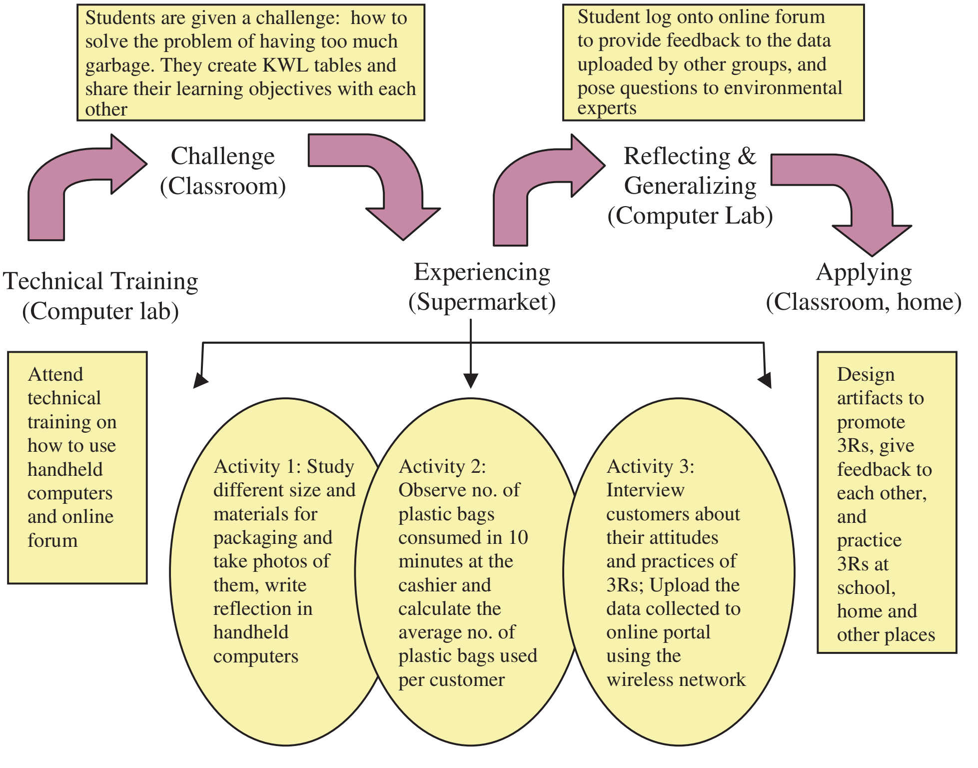


Figure 2. The instructional sequence and activities in chronological order.

to the class using their designed artifacts and represented their ideas in promoting the 3Rs.

4. Cognitive Tools

The handheld computer model chosen for this study is the HP RX3715 (Figure 3) running on Microsoft Windows Mobile 2003. The handheld is integrated with features like a 1.3 Megapixel digital camera, Wi-Fi connectivity, internet browser, voice recorder and text input functions. Tapping on the wireless network infrastructure in shopping centers, students can take pictures, collect data like interviews, key in information in their handheld computers, and upload them on the 3Rs online portal.

A customized Windows Mobile 2003 application was developed using Microsoft VB.NET, the Microsoft .NET compact framework and Windows SQL CE database. Each Pocket PC has a set of relational database tables to record the students' experiences, reflection and data collected by the students during the activity. The mobile application utilizes the HP IPAQ camera Software Development Kit (SDK) to integrate the camera functions with the application. Students can seamlessly take pictures within the application and have the images saved as reduced size JPEG format files on an expandable memory card inside the mobile device. The application aggregates and exports the students' experiences, reflection and plans, collected data and images into a HTML file (refer to Figure 10). The exported HTML file is stored on the expanded memory and can be transferred via the application to the school's Microsoft SharePoint Portal using Windows SharePoint Services over a wireless network.

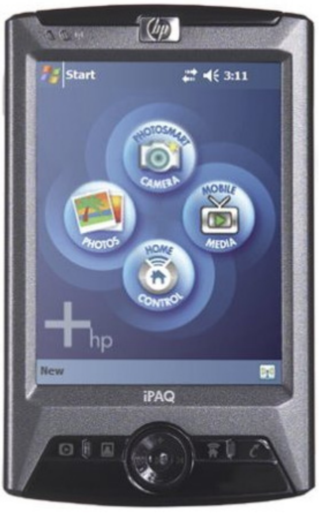


Figure 3. HP RX3715 Pocket PC.

The 3Rs software is designed to lead the students to carry out their learning tasks in the Challenge-Experiential Cycle. Next we will focus on the software design for the 3 field activities in the "experience" stage. Figure 4 shows the interface screen shots of the 3 activities.

When the student clicks on any icon buttons on the Experience Screen, they will first see a set of instructions before they begin their activity. These instructions clearly guide the students in how to conduct the activities in the supermarket. The software permits the pupils to step through this experiential stage in a spontaneous manner. They are allowed to select any of the three activities to embark on their experiential learning. Upon completion of all the activities, they would proceed to the next stage — *Reflecting*. The software lets the students step through the cycle in a structured manner.

The first activity was to study the different size and materials for packaging of products. Students chose from one of following categories of food items — milk, biscuits, or bread spreads, and recorded the types of packaging used by manufacturers in the chosen category. With the mobile device, they entered information about the packaging and took a picture of the packaging on the mobile device. They were able to annotate on their pictures stored on the mobile device. Figure 5 show the screen for Activity 1.

In the second activity, students stood near a supermarket checkout counter to collect data about the number of plastic bags and reusable shopping bags used over 10 minutes. They calculated the average number of plastic bags used per customer, and wrote their comments and reflections in pocket PCs. Figure 6 displays the Pocket PC screen for this activity.

The third activity involved students carrying out interviews with customers about their attitudes and practices of 3Rs. Four questions are provided in the Pocket PCs to guide students on how to interview the customers (Figure 7). The students read the questions from the mobile device and entered the customers' answers into the mobile device. Existing study also showed that a group of 8 years old Singapore students were able to use handheld computers to input words very well in their language subjects learning (Tan & Salleh, 2005). The data students collected reflected the collective reaction of the general public on this issue.

After the supermarket activities, the students reflected on their experiences in each of the activity (Figure 8.1). Reflection helped the students develop their logical reasoning, verbalize their thoughts and share their experience with others. They typed their reflections in the handheld computers. Students related what they have experienced to their own lives and the real world. They worked in group to discuss steps a family can take to create less adverse impact on the environment. They formulated a plan together on how they can implement the 3Rs in their own home. They were aided by prompts such as "Our plan is to . . . " and "The result of my plan is . . . " in the description and impact section of their plans respectively (Figures 8.2 and 8.3). In a student-centered learning environment, it is essential that learners

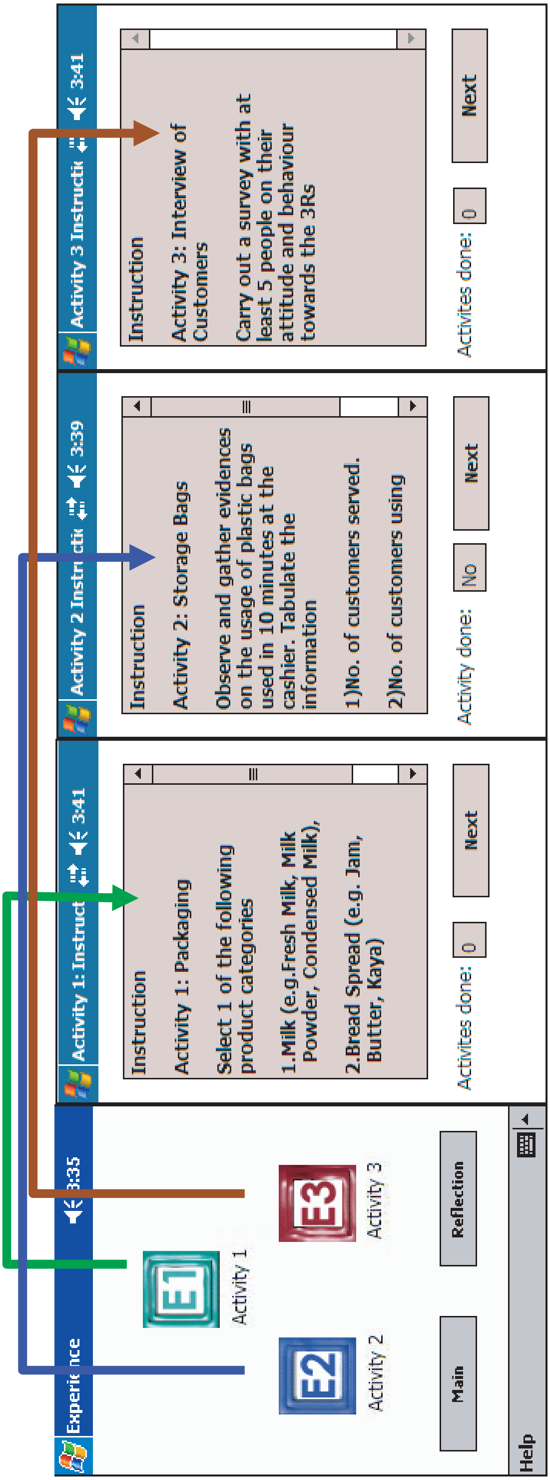


Figure 4. Experience screenshot and instructions of 3 activities.

Figure 5. Screenshot of packaging activity.

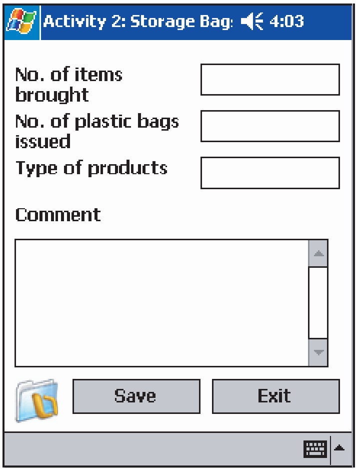


Figure 6. Screenshot of storage bag activity.

reflect on what they have done, why they took those actions and the strategies they employed in those activities (Iiyoshi, Hannafin, & Wang, 2005).

The students then generated a report of all the information and data collected on the pocket PC and uploaded the report to the online portal via the wireless network in a fast food restaurant nearby the supermarket. Students can use the application to generate a HTML report to view their work progress, their plans and actions (refer to Figure 10). This report can be uploaded to share with the other groups of students through the school's SharePoint portal. Figure 8.4 shows the interface for the students to upload the exported HTML file from the mobile device to the school's SharePoint Portal. A few students experienced difficulty in uploading their data on the online portal wirelessly due to the slow wireless connection at the fast food restaurant. However, these data were uploaded on the online portal when the students returned to the school.

The online portal was used to help students upload their experiences, reflections, plans, and applications of the 3Rs concepts from the mobile device to a web-based platform (Figure 9). This online portal, which includes a discussion forum, served as a shared space for all reports of the students uploaded from the mobile devices. It was also a platform for teachers and students to view the reports of all the groups, post questions, and exchange opinions. The discussion forum engaged the students in generating and processing information (Markel, 2001), through which they constructed knowledge.

The teacher posted the following question on the portal for all the students to answer: "What do you think of the 3Rs project? Look through the work of your friends and give them some comments about the work that they have done." Most students answered that the project was fun and they had a good team. One of the answers posted by the student reflected some of the learning that was

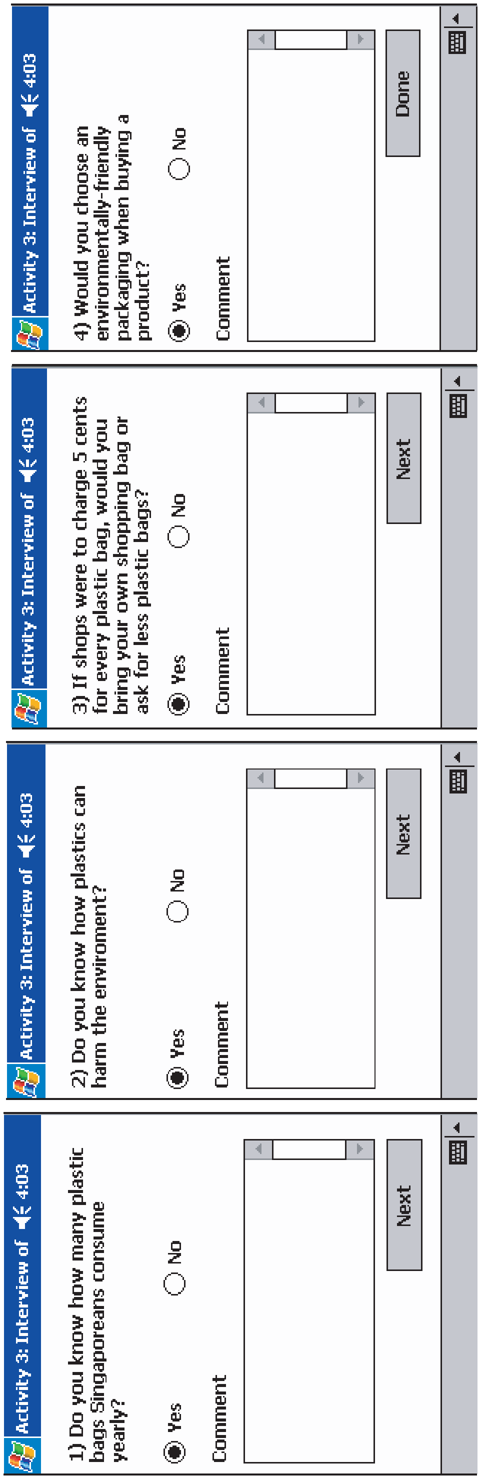


Figure 7. Screenshot of interview of customer activity.

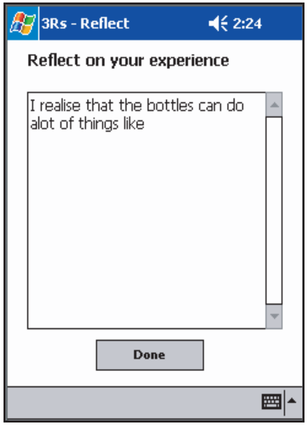


Figure 8.1. Reflect their experience.

Figure 8.2. Create a plan.

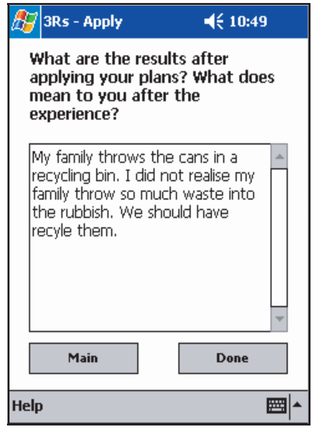


Figure 8.3. Applying 3Rs.

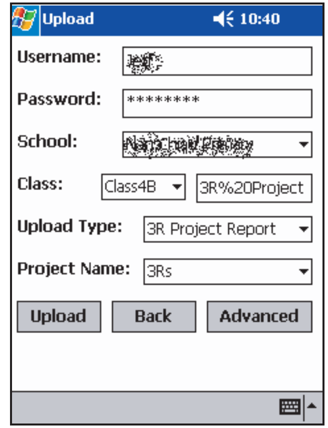


Figure 8.4. Upload report to the online portal.

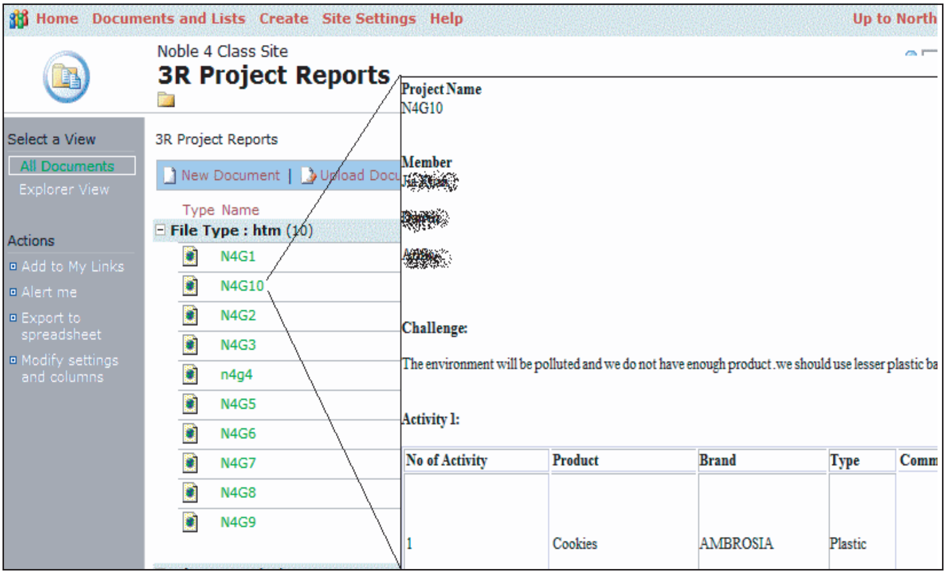


Figure 9. Students access the reports uploaded from the mobile devices on the school portal.

going on:

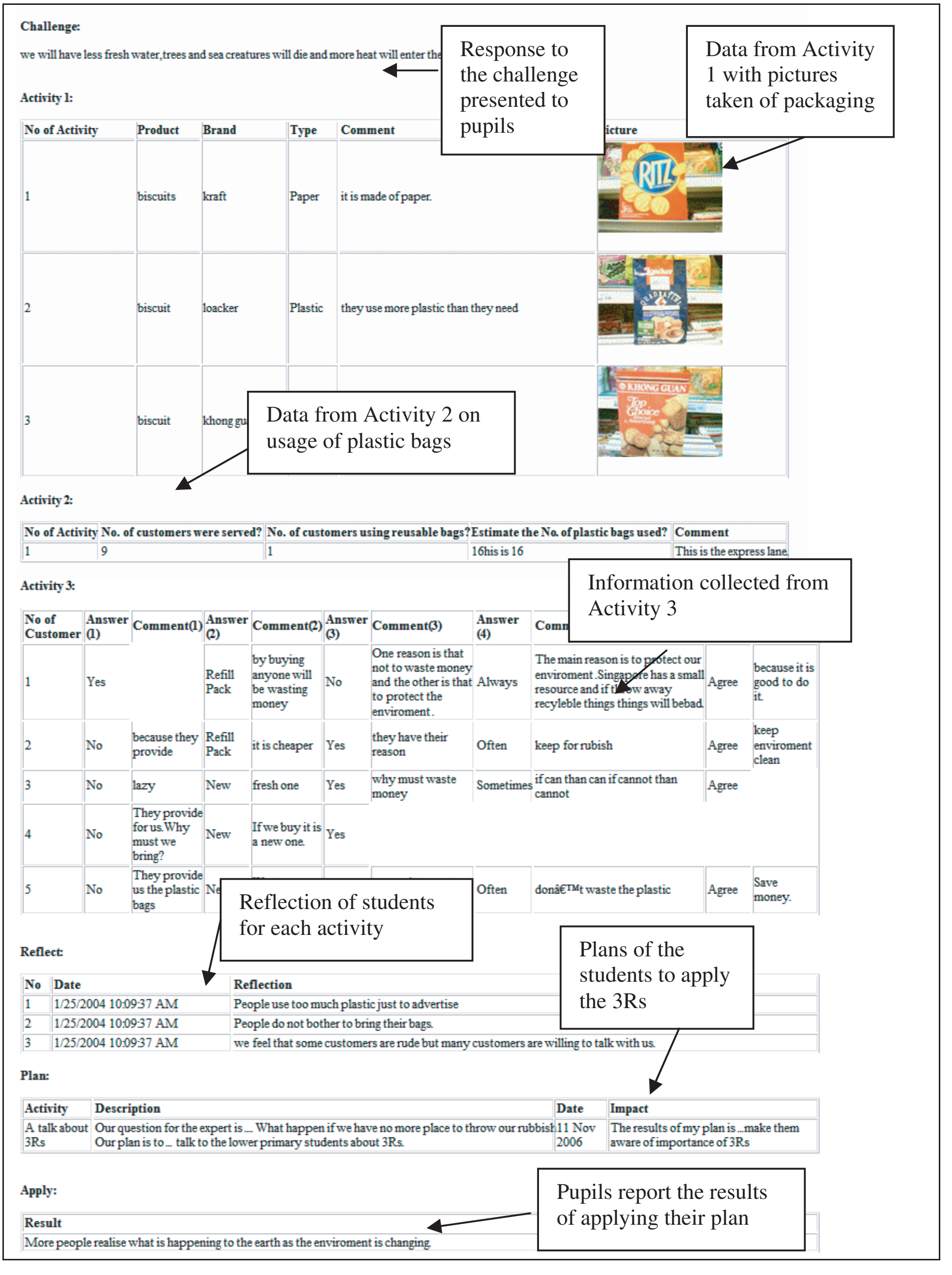
> "I think the 3Rs project helped me a lot. I am thinking to save more plastic bags and sometimes I bring my own plastic reusable bag. I also reuse my papers when I want to write workings for maths homework or even use it for non important word etc. After the 3Rs project I fell ashamed of myself. I cannot believe that I use lots of plastic bags. I am really thankful to have 3Rs project."

Students could also post questions to experts at the National Environmental Agency (NEA) on specific issues on the 3Rs. The following are some students' questions for the experts that reflected their thinking after going through the 3Rs project:

- How long does a plastic bag take to decompose?
- How can we reduce the usage of plastic bags to replace other materials or reusable bags?
- How long does it take for rubbish to be recycled?
- How can metal be decomposed?
- How do we recycle plastic?

5. Data Collection Methods

Data were collected to capture student understandings through the learning activities. Pre-activity and post-activity tests were conducted among the students to


Challenge:

we will have less fresh water,trees and sea creatures will die and more heat will enter the

Activity 1:

No of Activity	Product	Brand	Type	Comment	Picture
1	biscuits	kraft	Paper	it is made of paper.	
2	biscuit	loacker	Plastic	they use more plastic than they need	
3	biscuit	khong gu			

Activity 2:

No of Activity	No. of customers were served?	No. of customers using reusable bags?	Estimate the No. of plastic bags used?	Comment
1	9	1	16his is 16	This is the express lane.

Activity 3:

No of Customer	Answer (1)	Comment(1)	Answer (2)	Comment(2)	Answer (3)	Comment(3)	Answer (4)	Comm		
1	Yes		Refill Pack	by buying anyone will be wasting money	No	One reason is that not to waste money and the other is that to protect the enviroment .	Always	The main reason is to protect our enviroment .Singapore has a small resource and if throw away recyleble things things will bebad.	Agree	because it is good to do it.
2	No	because they provide	Refill Pack	it is cheaper	Yes	they have their reason	Often	keep for rubish	Agree	keep enviroment clean
3	No	lazy	New	fresh one	Yes	why must waste money	Sometimes	if can than can if cannot than cannot	Agree	
4	No	They provide for us. Why must we bring?	New	If we buy it is a new one.	Yes					
5	No	They provide us the plastic bags	Ne				Often	donâ€™t waste the plastic	Agree	Save money.

Reflect:

No	Date	Reflection
1	1/25/2004 10:09:37 AM	People use too much plastic just to advertise
2	1/25/2004 10:09:37 AM	People do not bother to bring their bags.
3	1/25/2004 10:09:37 AM	we feel that some customers are rude but many customers are willing to talk with us.

Plan:

Activity	Description	Date	Impact
A talk about 3Rs	Our question for the expert is... What happen if we have no more place to throw our rubbish Our plan is to... talk to the lower primary students about 3Rs.	11 Nov 2006	The results of my plan is ...make them aware of importance of 3Rs

Apply:

Result
More people realise what is happening to the earth as the enviroment is changing.

Figure 10. Report of the information, data and reflection of pupils generated in the mobile device.

find out whether they had gained better understanding of the 3Rs concepts. Pre-activity and post-activity surveys were conducted to examine students' attitudes towards handheld computers in their learning. Teachers and 8 target students were interviewed at the end of the activities to understand what they had learned about 3Rs, how they practiced 3Rs, and the role of technologies in their learning. We also examined the reports generated by each group's pocket PC, KWL charts created by the students and the questions posted on the online forum by the students. These artifacts may offer a glimpse in better understanding the learning outcomes.

6. Findings on Students' Learning

6.1. *Understanding of 3Rs content knowledge*

As for the content understanding of 3Rs, the students were asked to what extent they were concerned with environmental issues and to what extent they know about 3Rs. Table 1 shows some positive results in terms of students' perceived understanding of 3Rs.

It is shown in the table that there is significant difference in terms of how much students know about 3Rs between pre-test and post-test ($x^2 = 20.273, p < 0.01$). Before the 3Rs activity, 41% students reported that they knew the details of 3Rs. However, after the 3Rs activity, this figure increased by 33%. A majority (74%) students said they know the details of 3Rs. Considering that 3Rs topic is in Primary grade 6 Science syllabus, and the students are mixed-ability students, the fact that 3/4 of them know the details of 3Rs is satisfactory.

To validate the results of the students' self reported knowledge on the 3Rs, they were asked open-ended questions on their understanding of 3Rs in the pre-test and post-test. They had to define what each of the term meant and gave examples for each term. A sample question was "What do you understand by **Reduce**? Please give examples to explain." A score on a scale of 0–3 (0 = totally wrong or "I don't know", 1 = having a sense of the concepts, 2 = partially accurate, and 3 = accurate) was given to each definition and example based upon a coding scheme that was designed and agreed upon by the researchers. The full scores of the answers to the 3 definitions were 9. Two researchers coded the answers of the open-ended questions independently. Cohen's Kappa was used to measure the inter-reliability

Table 1. Analysis of the extent to which the student know about 3Rs ($N = 76$).

	Never Heard of It.	Heard of It, But Do Not Know What It Exactly Is.	Know What It Is, But Do Not Know the Detail.	Know the Detail About It.	x^2
Pre-Test	7 9.2%	10 13.2%	28 36.8%	31 40.8%	20.273**
Post-Test	0	5 6.5%	15 19.5%	57 74.0%	

Note: $^{**}p < .01$

Table 2. Paired-sample t test of students' overall understanding on 3Rs ($N = 75$).

	Mean	S.D.	t	Cohen's d	Hake's Gain
Pre-Test	1.95	2.05	−7.858**	0.95	0.30
Post-Test	4.07	2.35			

Note: $^{**}p < 0.01$

of the data coded independently by two researchers. The Cohen's Kappa was 0.76, which indicated fair to good agreement between coders. Paired-sample tests were employed to examine the difference of overall content knowledge on 3Rs between pre-test and post-test.

As shown in Table 2, the scores on the overall conceptual understanding of 3Rs increase significantly ($t = -7.858, p < 0.01$). The effect size was quite high (Cohen's $d = 0.95$). In addition, we calculated how much the students have been affected by the 3Rs activities relative to their prior knowledge indicated in the pre-test. Hake gain statistics (Hake gain = (Post-Pre)/(1-Pre)) (Hake, 1998) was used and medium gain was observed (Hake Gain = 0.30).

6.2. *Application of 3Rs*

At the end of the activity, each group presented a plan on how they would practice 3Rs in their home and school. One group decided to write to NEA officials a letter to promote 3Rs. In the letter, they briefly reported their findings of the 3Rs project, raised their concerns, and provided some suggestions on how to increase the awareness of 3Rs among the public. Another group made some posters on 3Rs and put them on the walls of the school corridor. When examining the artifacts created by the students, we see a lot of variety among students. Different students have different plans to practice and promote 3Rs. The qualities of the artifacts are quite good considering they are produced by ten-year-old students. Deep understanding of content knowledge was reflected in some of the action plans, which shows that students were able to internalize their understanding by creating action plans.

After creating their action plan, the students practiced 3R in many different situations. In the in-depth interviews that were conducted one week after the field activities, some students shared with us their practices. The results from the interviews revealed that the students did talk to their parents about the environment to influence them in conserving the environment. As shared by one of the students:

> "My family does not actually use reusable bags. It is always my mom who does shopping. Yesterday I told my father you should use and can always encourage my mom to use more reusable bags. He agreed with it and then he said that but sometimes we have a lot of things so we need to have some plastic bags to use. Sometimes we can keep these plastic bags."

One student talked about the recycling plan: "At home we use a mineral water bottle, we cut out... put a paint brush inside there that I can use that one to paint." Another student said: "I use rechargeable batteries and refillable pens. This way, we can reduce the number of batteries and pens we throw away." Another two students mentioned the change of their parents' shopping habit: "They will bring reusable bags when they are shopping. They did not do it before"; "They recycle plastic containers now!"

6.3. *Attitudes towards handheld computers for learning*

In the post-activity survey, the students were asked about their attitudes and perceptions toward the role of handheld computers in the learning activities compared with their traditional field trips, which are common learning activities for primary school students in Singapore. In the traditional field trips, students are often required to write their observations and thoughts on paper. The results of the post activity survey are shown in Table 3.

In general, students held positive attitude towards the use of handheld computer in the learning activities. They have very positive experience with the handheld computers during the activities. The majority of the students agree that by using the handheld computers in the learning activities, their field activities are more organized, they record information better, key in reflections better, and transfer information more conveniently. By using handheld computers in the learning activities, more than 3/4 students were interested and motivated in the learning activities. About 3/4 students agree that they learn content knowledge better by using

Table 3. Descriptive analysis of students' perception on the role of handheld computers in learning ($N = 76$).

	Strongly Disagree	Disagree	Agree	Strongly Agree
My field activities are more organized when I use the handheld computer.	2.6%	14.5%	42.1%	40.8%
I record information better when I use the handheld computer.	1.3%	22.4%	35.5%	40.8%
I key in reflections better when I use the handheld computer.	4.1%	14.9%	51.4%	29.7%
It is convenient transferring information from the handheld computer to portal.	7.9%	11.8%	52.6%	27.6%
I enjoy using the handheld computers for learning.	3.9%	3.9%	35.5%	56.6%
I am more interested when I use the handheld computers for learning.	5.3%	9.2%	28.9%	56.6%
I am more motivated when I use the handheld computers for learning.	4.0%	18.7%	42.7%	34.7%
I know more about the content knowledge because of using the handheld computer.	6.6%	22.4%	36.8%	34.2%
The handheld computers help me learn better.	5.3%	12.0%	41.3%	41.3%

handheld computers. More than 90% students enjoyed using the handheld computers in learning.

The teacher held positive view towards handheld computers in support of student's learning as well. As shared by one of the teachers in the interview,

> "[by using Pocket PCs], they [students] are interested in it, they are engaged in it, they are more motivated and excited about it .... It's much easier to use a Pocket PC because everything is there, it's less of a hassle; you do not need to take out a pen and pencil and writing and all that .... It [pocket PC] allows students to have a feel of being independent in their learning, ... where at least they feel the responsibility of completing the task and the responsibility of learning is on them .... Here the sense of responsibility is there .... Collaboration is also there. This also encourages communication among students when they are outside, you know when they make comments among each other, they will pass remarks, and best of all, make decisions, about what to do; what pictures to take, which materials to choose."

The data analysis shows positive student learning outcomes of 3Rs when using the handheld computers in the activities. Students' content knowledge on 3Rs increased substantially, and they believed that the learning gains were much credited to the use of the handheld computers. The students intuitively and enthusiastically adopted the handheld computers in their learning activities and showed little resistance to using it for learning. They took more responsibility for their own learning and were in turn more interested, motivated and engaged in learning. With the handheld computers, students perceived that their learning activities are more organized as a result of the complex processes made simple with the use of cognitive tools. The Challenge-Experiential approach is useful in engaging the students to learn about the 3Rs. It provided rich experience for the students to understand the concepts and internalize the concepts through reflection, planning and application. Two parallel studies conducted in 3Rs project schools showed similar learning outcomes (Seow *et al.*, 2008; Zhang *et al.*, 2006).

Throughout the data analysis, we found that different activities in the field trip had different impacts on the students' learning. For example, interviewing the public on plastic bag usage seemed to have a stronger effect on their learning, than observing/taking pictures on the packaging material did. The latter activity, designed to help students understand how manufacturers excessively over-package their products and create wastage, was not appreciated by the students, who instead took pictures for fun. Improvements could be made to add follow-up questions to encourage the students to think more deeply about the packaging issue. In addition, we found that most student discussions in the online portal were still at a surface level. They needed more scaffolds to exchange opinions and critique others' work better. We will further improve the curriculum and pedagogy design in the future.

7. Discussion and Conclusion

This study is about the application of handheld computers as cognitive tools for students' authentic learning of environmental issues using a challenge-experiential learning approach. In their study on the use of computers as cognitive tools, Jonassen and Reeves (1996) identified critical criteria for qualifying a software tool to be a cognitive tool, that it scaffolds intentional learning and meta-cognition, allows students to construct knowledge, is generalizable to content in different subject areas, engages learner in critical thinking about subjects, develops skills transferable to other subjects, significantly restructures or amplifies thinking, and facilitates collaboration and distributed cognition. The handheld computer software in 3Rs project meets these criteria well.

First of all, handheld computers together with the 3R software application scaffold students' intentional learning and meta-cognition. The Challenge-Experiential model in the handheld application allows students to participate in a series of inquiry activities. In the learning cycle of the handheld application, the students are presented with a challenge, and they articulate the learning goals, collect data, review the aggregated information, reflect, and make decisions on the strategies to solve the problems. With the learning cycle integrated in the handheld applications, the students were provided a structure to scaffold their learning. This cognitive tool makes the learning more student-centered. As time goes on, the learning cycle can be internalized by the students so that their processing skills improve.

Handheld applications allow students to construct knowledge. Before the project, students created KWL charts and presented their prior knowledge on 3Rs. They integrated new experiences on the 3Rs by using handheld computers for the rapid collection of data. The handhelds also support self-reflection forming part of the knowledge construction process (the handheld computers represent what students know, not what the teachers know), though which students make meaning on 3Rs by integrating new experiences and interpretations with their prior knowledge about the world and constructing their own simple models to support what they observe.

The handheld computer is a knowledge representation and reflection tool that engages students in critical thinking about subjects. The use of the handheld computer allows greater opportunities for learning in context of the subject that otherwise would not be possible in the classroom. For example, students in the supermarket observed and recorded types of packaging, collected data on plastic bags used at the cashier and interviewed the public on their perspectives on environment. The handheld computer serves as cognitive tool to engage the students in thinking about the environment during the data collection process. Students looked at data from different groups in the online portal. Then they analyzed the data and came up with critiques and feedback, which facilitate their critical thinking.

Handheld applications help amplify students' thinking by supporting and guiding the thinking process of the students throughout the field trip. Thus learning activities are more organized as a result of the complex processes made simple with the use of handheld tools. The handheld tool brings more effective use of the mental efforts of the students by offloading unproductive memorizing tasks such as the procedure of tasks. In this study, the handheld computers functioned as intellectual partners in the learning activities. In the intellectual partnership, the students assumed responsibilities to recognize and judge information, and then organize it, while the handheld computers were deployed to store and retrieve information, and organize information, which are the tasks that computers perform better than humans. The affordance of sharing data and group knowledge from handheld computers with the class through the online platform can help students to restructure their understanding. Students were able to visualize their thinking and restructure their ideas when involving in online activities. This helps students integrate and interrelate ideas, which in turn make the ideas more meaningful.

The handheld computers and the online portal mediated students' collaboration and distributed cognition occurring across activities, artifacts, within group and across groups. The online portal is a shared workspace for all the students to share data, reflections and ideas. Students are able to view the information and data generated by other students. They provide feedback to other groups' data, question each other's beliefs and argue about the meanings, which in turn build community knowledge. Therefore, in this technology mediated learning environment, knowledge on 3Rs is not an object that is acquired and possessed by individuals, but embedded in the conversations and social discourse.

The features of handheld computers such as data storage, camera features and Internet capability, and the model of the software application (e.g. the challenge-Experiential learning cycle) are affordances that can be generalized to content in different subject areas. The handheld applications help develop students' skills transferable to other subjects as well. Students need to develop skills to conduct their own scientific inquiry independently and collabratively. The design of the handheld computer software provided a structure for the students to follow the sequence in the learning cycle. This sequence of learning can facilitate new form of thinking and reasoning skills, which can be transferred to learning other subjects. The learning tasks structured by handheld computers are situated in meaningful real-world contexts. The inquiry skills developed through going through the activities are generic skills that are transferable. Therefore the handheld applications are interdisciplinary tools that can facilitate the transfer of knowledge across domains.

Handheld computers have enormous implications for students' learning, and educators need to transform traditional approaches to curriculum to exercise their full potential. When thinking and designing learning activities using mobile technologies, we need to focus more on the learners than the technologies. This is in line with Sharples, Taylor and Vavoula's (2005) approach of mobile learning — not focus on mobile technology but on the learners being mobile. It should be noted that it is not only the technology affordances but also the way the technologies were appropriated in the learning environment that enables handheld computers to serve their purpose as cognitive tools. Learning occurs as a result of using technology as mediating tools over curriculum and pedagogy. Without appropriate curriculum and pedagogy design, handheld computers may not function as cognitive tools as expected.

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