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Affordances of mobile technologies for experiential learning: the interplay of technology and pedagogical practices

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Abstract Experiential learning is the process of creating knowledge through the transformation of experience and has been adopted in an increasing number of areas. This paper investigates the possibility of technological support for experiential learning. A learning activity flow (or script) and a mobile technology system were designed to facilitate students in experiential learning. An experiment was conducted on two fifth-grade classes at an elementary school, one class using personal digital assistants (PDAs) and the other working without them. The results indicate that mobile technologies are effective in improving knowledge creation during experiential learning. The interplay between the mobile technology affordances and the proposed learning flow for experiential learning is thoroughly discussed.

Keywords affordance, experiential learning, mobile learning, mobile technology, PDA.

Introduction

Dewey's (1938) 'learning by doing' theory emphasizes the value of action while learning. From an experiential learning perspective, learning is a process in which knowledge is created through the transformative experience (Kolb 1984; Kaagan 1999). Optimal learning occurs when people are able to link past experience with new concepts they want to learn (Kolb 1984). Experiential learning utilizes learning activity in which learners encounter tangible learning contexts rather than abstracted knowledge (Pimentel 1999). To date, experiential learning has been applied in numerous fields (Kayes 2002). However, the utility of experiential learning has been questioned by some educators (Reynolds 1999; Miettinen 2000; Kayes 2002). In an authentic learning context, can students be motivated to learn effectively without any careful design or guidance? (Lai *et al*. 2005) Experiential learning is generally regarded as lacking a mechanism to focus student awareness in a learning context (McMullan & Cahoon 1979; Miettinen 2000). Thus, our purpose is to attempt to provide technical support to facilitate experiential learning.

With the rapid advancement of technology, there has been an increase in the quantity of research into applying mobile technologies to learning. The G1:1 project (Research Center for Science and Technology for Learning 2005; Chan *et al*. 2006) and the M-learning project (ULTRALAB and CTAD 2003) are examples of this. Researchers have argued that mobile technologies have created many new exciting opportunities for learning (Curtis *et al*. 2002; Kynäslahti 2003; Ogata & Yano 2004). As for support of mobile technologies for

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experiential learning, this was a theme of the MOBIlearn project (Hsi 2003; MOBIlearn consortium 2003; Sharples *et al*. 2005). Most research in the field of mobile technologies claims benefits to learning based on evidence of learning achievement. However, the interactions that exist between learning and these technologies are complex and varied (MOBIlearn consortium 2003). Learning occurs as a socio-cultural system, within which many learners interact to create a collective activity framed by cultural constraints and historical practice (Sharples *et al*. 2005). In our study, personal digital assistants (PDAs) together with attendant embedded functionality are incorporated into an outdoor learning flow activity in order to examine in what ways and to what extent experiential learning of elementary school students can be facilitated. In the following section, we introduce how we regard mobile technologies as an opportunity to enhance experiential learning. Then the concept of affordances will be introduced to evaluate the effectiveness of mobile technology supporting experiential learning.

Experiential learning

Experiential learning utilizes experience in a unique context to facilitate knowledge acquisition and creation. The learner engaged in experiential learning is in direct contact with the subject being studied (Kolb 1984). During experiential learning, learners are able to ground their understandings and new discoveries within their own previous concrete experiences to construct ideas and relationships actively in their own minds (Barab *et al*. 2002).

Though numerous experiential learning theories have been proposed, Kolb's experiential learning theory (ELT) remains very influential (Vince 1998; Oxendine *et al*. 2004). Kolb's ELT focuses on experience, which functions as the primary force-driving learning, as knowledge is constructed via transformative reflection on one's experience (Barker *et al*. 2002). Based on Kolb's ELT, experiential learning can be regarded as a four-stage cycle. These four adaptive learning stages are: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb 1984). To illustrate this, the learners begin with a concrete experience, upon which they develop observations and reflections. Following this period of reflective observation, learners weave their thoughts together to construct abstract concepts that can guide future actions. Once developed, the learners actively test their constructs, which in turn, leads to new experiences and renews the learning cycle (Barker *et al*. 2002).

Based on Kolb's ELT, some researchers have applied varied computer-supported tools to implement their experiential learning activities. For example, visualization mechanisms have been incorporated to cause learners to interact with authentic and complex phenomena (Christian 2003). Others made suggestions on how to improve the learning procedure. For example, Trindade *et al.* (2002) argued that writing observation outcomes down is important for reflection. Learners can thus compare knowledge acquired with supplementary material because they can make sense of what they see with the aid of such things as annotation, filters and reference materials (Whitelock *et al*. 2000). At the end of the activity, synthesizing knowledge can be a good strategy to supplement for possible passive observations (Jensen 2004).

Although experiential learning has been applied in many educational fields, it has not escaped critical assessment (Reynolds 1999; Miettinen 2000; Kayes 2002). For example, McMullan and Cahoon (1979) noted that experiential learning has two weaknesses: it lacks a mechanism for focusing awareness in the learning context (Miettinen 2000); and students pay insufficient attention to abstracting from experience (Vince 1998). Based on these factors, we will design a system to eliminate such weaknesses by utilizing mobile technologies and to investigate the affordances of such technologies in experiential learning.

Educational affordances of mobile technologies

Mobile technologies are quickly becoming indispensable. In terms of educational application, mobile technologies can be viewed as a service that electronically delivers general and educational content to learners regardless of location and time (Lehner & Nosekabel 2002). It can also support learners in authentic and seamless learning. Mobile technologies provide instant learning guidance and feedback and use new interfaces for diverse learning approaches (Liang *et al.* 2005). In particular, some studies pointed out that mobile technologies are helpful on field-trip-based and outdoor learning (Rieger & Gay 1997; Chen *et al*. 2003; Roschelle 2003; Seppälä & Alamäki 2003).

Mobile devices, especially handheld computers, may become an increasingly compelling choice of technology for classrooms (Soloway *et al*. 2001; Tinker & Krajcik 2001). Therefore, in this study we consider PDAs as an exploratory tool. Mobile technologies provide instant recording functionality for note taking equipped with plug-in cameras and sound recording functions. By utilizing computing power and wireless capability, these mobile technologies can make learning expedient, immediate, authentic, accessible, efficient and convenient (Curtis *et al*. 2002; Kynäslahti 2003; Ogata & Yano 2004). With the mobility of such devices, typically palm-accessible and within arms' reach, learning can be achieved in much the same way as with their predecessors – pencil, paper and calculator (Soloway *et al*. 2001).

The term affordance, originally proposed by James Gibson in 1977, refers to the relationship between an object's physical properties and the characteristics of a user that enables particular interactions between user and object. From Gibson' definition, 'the affordance of anything is a specific combination of the properties of its substance and its surfaces with reference to an animal' (Gibson 1977, p. 67). Educational affordances are those characteristics of an artifact that determine if and how a particular learning behaviour could possibly take place within a given context (Kirschner 2002). Educational affordances can be defined as the relationships between the properties of an educational intervention and the characteristics of the learner that enable particular kinds of learning by him or her (Kirschner 2002).

Mobile technologies can provide various educational affordances and, in this study, the following ones were examined. First, mobile technologies 'afford' real-time information whenever and wherever learners need it. The real-time information can be provided by the PDA to support both learning flow and to provide learning materials. The former guides learners along a productive course and prevents straying from their objectives or getting lost in the learning environment. The latter provides learners with readily accessible relevant materials thus encouraging sustained exploratory learning. Second, mobile technologies 'afford' a rapid access interface for note taking, such as photo taking and sound and video recording. These notes can serve to aid in retention when out of the learning environment.

Mobile technologies provide diversely within-arm-reach and rapid interfaces of note taking for imagery and verbal approaches. However, the question is whether learners will be able to recognize and implement these capabilities and realize these enhanced learning potentials in an outdoor classroom in an experiential learning context. This study aims to investigate how the properties of these mobile technologies are perceived by the learners and how they affect the implementation of the learning flow. This study has three goals. First, to develop a system combining mobile technologies to support experiential learning. Second, to design a learning flow for experiential learning in a school garden in which students are guided with the facilities of PDAs. Third, to conduct an experiment to compare the knowledge creation of two groups of fifth-grade students, one equipped with PDAs and one without PDAs. The benefits and pitfalls of mobile technologies in experiential learning are discussed as well.

Experiential learning activity design and system implementation

Learning flow

In this study, we develop a mobile technology embedded learning flow to support field-trip learning based on the aforementioned experiential learning procedures in the following six stages.

Photo taking

To capture the features of plants concretely and efficiently, and to collect data for their retention, students were provided with plug-in cameras of PDAs to take photographs. The cameras could record the visual information quickly and gather that information to capture authentic and complex phenomena. These photographs may aid students in recalling information acquired in the learning environment.

Sensory experience

During the second stage, students obtained sensory experience as PDA prompts led them to 'feel' the plants using various senses – such as taste, hearing, touch, smell and sight. After this concrete experience, students were required to record their impressions on their PDAs.

Further observation

In the further observation stage, prompts from the PDAs directed students to observe more deeply than in the previous stage, and again instructed students to record these observations. If students needed background information, they could access online learning material through their PDAs.

Comparison

In the comparison stage, 'trap-setting' statements, mixing correct and incorrect descriptions of observation targets, were presented on the PDAs. The inclusion of trap setting statements was to cause students to compare these assertions with their own observations. Through practical observation, students would be able to determine whether these statements were correct. Students were also asked to record their observation results if they differed from the statements on the PDAs. The statements were designed to stimulate confusions between the materials provided and the direct observations.

Question proposing

This stage guided students in developing questions based on these confusions as well as their observations. Students could then, conveniently and quickly record their questions orally using the sound recording function of their PDAs. The aim of the comparison and question proposing stages were to make students reflect and restructure their cognitive schemas in an effort to reach a refined and deep conceptual understanding.

Final report

After field observations, the students returned to their classroom and wrote paragraphs – their final reports – documenting what they learned about the observation target. These paragraphs were to be placed on plant information plaques composed individually, one by each student. During this process, students were able to refer to their photographs, recorded vocal questions and observation notes. The goals of this stage were to help students organize the knowledge formed in the whole field-trip learning activity and to encourage them to conceptualize.

As the major goal of this study is knowledge creation through experiential learning, it focuses upon the last two stages, namely question proposing and the final report. Prompts on the question proposing stage lead students to reflect and propose conflicts and questions during observation. In the final report stage, students engage in synthesizing knowledge created from previous learning stages.

Support system for experiential learning

The aim of the proposed system is to support experiential learning for teachers and students. For teachers, the system provides authoring and monitoring interfaces. Through the authoring interface, teachers can design prompts and learning materials. That is, teachers can design their own prompts or quizzes, such as knowledge about dinosaurs or aquatic plants – according to the instruction requirements. They can also develop learning materials to support students' individual learning and to aid students in tackling problems when responding to quiz questions. The monitoring interface provides a comprehensive picture of the learning status of students in the class, whereby teachers can understand student learning results and progress. Teachers can also instantly assist specific students who encounter learning difficulties.

For students, the system presents prompts to guide them. First, students follow the prompt to the right location or learning target, such as a particular plant. They then seek answers with the PDAs and respond to the quizzes on their PDAs. During the learning processes, students explore knowledge via an authentic field trip and immersion in the environment. Additionally, students can examine and consider the learning progress of other students through real-time information sharing on the PDAs.

The system is run in a web-based environment and is implemented by PHP and MYSQL on a LINUX operating system. The system consists of one database and four modules. The database stores quizzes, prompts, students' personal information and learning portfolios. These four modules are described below.

Authoring module

Teachers may need to develop the quiz and learning content prior to conducting mobile learning activities. The authoring module provides interfaces that allow teachers to design learning material, either independently or in collaboration with other instructors, if that feature is enabled. Teachers can therefore share ideas with each other. Quiz question types include multiple choice, blank filling and open-ended questions. This module enables teachers to design items using various different media, including text, images, audio and animation.

Problem-proposing module

The problem-proposing module uses a mechanism for students to be guided by items transmitted in real-time from the server via a wireless connection. Typically, an item includes a learning prompt and a question. Response format choices are selecting an appropriate answer, filling in a blank, writing an answer in free form, drawing a picture, recording sounds, or even taking a picture with the PDA plug-in cameras.

Learning status module

For teachers, the learning status module displays the real-time learning status of all students, including learning performance and portfolio. The teacher can monitor the learning status of the whole class and monitor the progress of specific students as well. For students, the module provides their own learning status as well as that of their peers.

Multimedia management module

This module handles saving, uploading, downloading and displaying multimedia information, including sound, image, video and text.

This study focuses upon the learning guide and note taking. The infrastructure of this mobile technology provides wireless connection and the interfaces for note taking, including typing, writing by hand, sound recording and photo taking. The proposing system supports interfaces for teachers to design prompts and learning material. It also presents these to students and manages their multimedia notes.

Method

This experimental study was conducted to justify the hypothesis that mobile technologies can increase the level of knowledge creation through experiential learning beyond that which is achieved with traditional methods (paper and pencil).

Participants

Students in two fifth-grade classes at an elementary school participated in this experiment. The study compares the progress of 34 students, 16 boys and 18 girls, in one class using personal PDAs with plug-in cameras, and 32 students, 16 boys and 16 girls, in another class using paper and pencil. These two conditions are identified as 'with PDA' and 'without PDA'. The same natural science teacher taught both classes.

Procedure

The experiment consisted of several sections: pre-test, main activity, post-test and questionnaire. Students were initially given a pre-test. The 'with PDA' students were then given an additional 90-min course on the use of the PDAs. This course was not given to the 'without PDA' group. In the main 90-min instruction section, students were taught about the African Touch-me-nots (*Impatiens walleriana*) in the school garden. First, the teacher briefly introduced the learning environment, learning content and learning flow to the students. It took roughly 5 min. Students then followed a learning flow to explore the African Touch-me-not under the guidance of prompts – on their PDAs for students with PDA, and on paper for those without PDA. In stage one, photo taking, students with PDAs used the digital cameras to take photos, whereas the other students drew pictures with paper and pencil.

During stages 2, 3 and 4, the two classes of students took notes and referred to learning material on the PDAs or paper depending on the condition they were in. The learning material was co-designed by the science teacher and the first author based on the curriculum standard issued by the Ministry of Education in Taiwan. During the question proposing, stage 5, the students with PDAs recorded spoken questions using their PDAs while the students without PDAs wrote their questions down on paper. During the last stage, the final report, students with PDAs created information plaques by referring to the photographs, spoken questions and the observation notes they had recorded on their PDAs, whereas students without PDAs referred to the sketches, written questions and observation notes they had recorded on paper. After the outdoor activity, students took a post-test and filled in a questionnaire in the classroom.

The pre-test and the post-test were identical and consisted of eight multiple-choice questions about African Touch-me-nots (see Appendix I). The final reports were analysed as follows. Treating each sentence as a unit for analysis, the descriptions in the final report of each student were sorted into two categories: statements that were inspired by prompts and statements created in the process of field-trip observation. The former were those

Table 1. *t*-test statistics related to the effects of learning achievement.

	With PDA		Without PDA		*t*-value
	M	SD	M	SD	
Pre-test	3.06	1.01	3.19	1.71	
Post-test	6.68	0.98	6.06	1.61	
Post-test – pre-test	3.62	1.04	2.88	1.91	1.94*
N	34		32		

*$P < 0.05$.
M, mean; SD, standard deviation.

that had been mentioned before, in prompts or in the learning materials provided, either by their PDAs or in the paper handouts. The latter dealt with concepts that had not previously been mentioned. The descriptions attributed to field-trip learning can thus be identified as being in one of these categories. The study assumed that students with PDA, through the assistance of mobile technologies, would acquire more knowledge than would students without PDA. Therefore, one-tailed *t*-tests were conducted in this study.

The questionnaire, composed of 37 items and some open-ended questions about students' attitude towards the learning flow in general, and the supporting technology in particular, was then filled out and submitted. One trick question which is opposite in meaning to another item in the questionnaire was included to help determine the validity of students' responses. The questionnaire was composed of four parts: learning performance, user interface, motivation, and attitude towards the design of the activity and primarily used a 5-point Likert scale (5 indicates strong agreement and 1 indicates strong disagreement) but some open-ended questions were also included. There were 30 items in the common questionnaire, while the PDA group received seven additional questions related to PDA-specific experiences. In the present study, we pay particular attention to comparing the learning flow of the two groups, one of which used mobile technology.

Results

Knowledge gains

This study examined the effects of mobile technology support on knowledge gain by comparing the two different classes. No significant difference existed between two groups' pre-test scores (average score 3.06, 3.19; $t = -0.37$, $P > 0.05$). The effects of learning achievement are shown in Table 1. The resultant learning achievement scores of the group with PDA were significantly higher than those of the group without PDA. We can therefore conclude that the group with PDA retained more knowledge than the group without PDA.

As an experiential learning activity, knowledge gain was just one of the objectives. To scrutinize how students built knowledge in experiential learning, we further analysed the final reports of the two classes. Each statement in the final reports was treated as a unit of analysis and classified into one of two categories: knowledge acquired and knowledge created. The results (see Table 2) indicated that, in terms of the number of descriptions already mentioned in related materials, no differences existed between the two classes. However,

Table 2. *t*-test related to final report.

Variables	With PDA		Without PDA		*t*-value
	M	SD	M	SD	
Knowledge acquired	4.29	1.87	4.25	1.90	0.07
Knowledge created	2.74	2.46	1.81	1.82	1.74*
N	34		32		

*$P < 0.05$.
M, mean; SD, standard deviation.

in terms of the number of descriptions freshly generated during the experiential learning process, the students with PDA created more knowledge than did the students without PDA.

The following excerpt from a with-PDA student's final report was an example of the knowledge discovered via experiential learning.

> The African Touch-me-not is alternate. *It has four petals*. The petals are usually pink. *There is an object that looks like a pistil surrounded by four petals*. The leaves of the African Touch-me-not do not grow hair. The shape of leaf fringes is saw-toothed. *The vein is clearly visible*. It is soft to the touch. The plant stem does not grow hair. The stem is firm rather than soft and juicy. *The seeds are dark green before they become big heavy pods. They are light green before becoming big heavy pods. If you click seeds softly, they will explode out*.
> P.S. *The petals are heart-shaped*.
> You should go to see it for yourself!

The above italicized statements reflect the knowledge this student has created during the process of experiential learning with the support of a PDA. For example, statements such as '*It has four petals*', and '*There is an object that looks like a pistil surrounded by four petals*', were not mentioned before in any learning materials provided. That is, the student made discoveries in greater detail while using a photo-taking technique to explore the plant. Later, when developing the information plaque as her final report, the student referred to the photographs and wrote a very detailed description. Furthermore, some statements clarified what she had observed, for example the statement 'the stem of the plant does not grow hair. The stem is firm instead of soft and juicy' showed that she was not misled by spurious online materials designed to detect any absent-minded observations. Rather, she entered correct statements. Apparently the 'trap-setting' prompts designed in the PDAs during experiential learning had made students reflect and cognitive schemas and reach a refined and deep conceptual understanding. Notably, the girl's descriptions showed that she was engaged while observing a plant. The statements, '*The seeds are dark green* before *becoming big heavy pods*.' and '*They are light green before they become big heavy pods*.' demonstrate that she observed not only one single seed but also paid attention to the seeds at different stages of growth.

In summary, this excerpt showed that the student was able to generate knowledge about the features of the plant she observed in substantial detail. Based on this exemplary information plaque, we may assert that mobile technologies have the potential to support experiential learning in a very productive way.

Mobile technology

Based upon responses to the trick question, it was determined that 27 and 28 copies of the questionnaire were valid in the classes with and without PDA, respectively.

Mobile technologies provide real-time learning material and learning prompts for learners. Sixty-three per cent of students responded that the learning material had been helpful in learning in an outdoor classroom. It was also found to be helpful in the abstract conceptualization stage where scaffolding is necessary for the formation of abstract concepts in the knowledge creation process. The latter is discussed in the following section, The support system.

For students with PDAs, the system provided a flexible and responsive interface that facilitated photo taking, recording, touch-screen writing, etc. The results reveal that the photo taking and sound recording interfaces impressed the students. These two interfaces are discussed below. The questionnaire results indicated that students agree strongly (mean = 4.33) that the taking of photos made learning more efficient. Compared with sketching, photo taking had four principal advantages. First, 'photo taking can record information quickly'. Several could be taken in the time it takes to draw one minor aspect of the plant. With the ability to take multiple photos, students are able to compare characteristics using multiple images and can conduct more extensive observations in a shorter period of time. Second, the digital photos could be manipulated digitally producing useful results, including magnification of specific parts of a feature. Among the text responses of students were 'the photos could magnify image, I can see it clear', 'it can take a photo on very near objects' and 'it can take the important points'. Third, digital pictures are easy to save and manage. When leaving the learning environment or after a period of time, students could easily recall the subject with the assistance of the images. Lastly, not all students enjoyed drawing pictures. Students overwhelmingly preferred taking photographs to drawing pictures (average score for taking photographs mean = 4.74, and for drawings mean = 3.32; $t = 5.21$, d.f. = 53, $P < 0.05$). Twelve out

Table 3. Questionnaire results about the learning prompt of the two classes.

Question	With PDA		Without PDA		Z
	M	SD	M	SD	
1. Guided by the learning prompts, I feel better directed in outdoor activities.	4.67	0.62	3.96	0.90	–3.32*
2. Guided by the learning prompts, I feel very interested in outdoor activities.	4.56	0.58	3.96	1.04	–2.40*
3. Guided by the learning prompts, I feel deeply engaged in learning.	4.19	0.79	3.71	1.12	–1.71*
4. The learning prompts helped me to observe more varieties.	4.33	0.68	3.96	0.87	–1.97*
5. The learning prompts helped me to observe in great detail.	4.30	0.72	4.07	1.05	–0.71
6. The learning prompts helped me to generate questions about the plants that I observed.	4.00	0.78	3.85	0.95	–0.64
7. The various functions (photo-taking/sketching, sound-recording/none, making comparisons, open-ended questions, multiple choice questions) and responding to the prompts, make learning more attractive.	4.41	0.84	3.93	0.81	–2.45*
8. The various functions (photo-taking/sketching, sound-recording/none, making comparisons, open-ended questions, multiple choices) and responding to prompts make learning more effective.	4.33	0.78	3.89	0.96	–1.94*
Total	4.35		3.92		

*$P < 0.05$, one-tailed Mann–Whitney U-test.
M, mean; SD, standard deviation.

of 28 students without PDA thought drawing was the most frustrating aspect of the exercise and the most frequently cited reasons were that students did not like or were not good at drawing pictures. To sketch the characteristics of plants, students have to be trained over a period of time. In addition, the act of sketching places increased attention demands upon the student which, in turn, increases the cognitive load. Hence, plug-in cameras appear to be of significant assistance to students during experiential learning, and, in particular, improve retention. However, the convenience and quickness of photo taking may distract students from the results of their observations. It is necessary to recall and organize the observation results from the photos as was done in the proposed final report in this study.

In terms of sound recording, most students believed that it was easy and quick compared with writing by hand. Students strongly agreed that such functionality can aid learning (mean = 4.24) and most students enjoyed the process (mean = 3.84). Sound recording can aid students in proposing more questions and thus solving knowledge conflicts in abstract conceptualization (average number of proposing questions for PDA group was 2.38, and 1.63 for the group without PDA; $t = 1.74$, d.f. = 64, $P < 0.05$). The functionality of sound recording, therefore, increased knowledge creation. However, a minority of students argued that sound recording was inconvenient. They cited the following reasons: 'I must rerecord if they want to modify'; 'I may be interfered with by other students'; 'I do not feel free because the sound recorded from PDAs is less virtual'; and, 'the qualities of recorded sound are affected by noise in the background'.

The support system

The questionnaire results referring specifically to the support system for prompts (see Table 3) indicate that the effectiveness of learning prompts – PDA embedded or in handout form – differed significantly between the two classes. In the 10 questions using the 5-point Likert scale survey, the mean for students with PDA was 4.35, and the mean for the students without PDA was 3.92. Students with PDA also scored significantly higher than the group without PDA in most items.

The results of items 1 and 2 revealed that students with PDA were more motivated than were students without PDA. The motivation may well have been inspired by the novelty of the PDA, which is a new piece of technology for students. The results of items 3 and 4 indicated that the note-taking approach of the PDA saved time and this translates into the ability to conduct more observations and improved knowledge gain. The results of items 7 and 8 also revealed that the PDA interfaces increased students' motivation and learning achievement. However, results of items 5 and 6 showed

Table 4. With-PDA versus without-PDA students' feedback on the six-stage learning flow.

Items Stages	Helpful (%)		Frustrated (%)		Like (%)		Dislike (%)	
	With PDA	Without PDA	With PDA	Without PDA	With PDA	Without PDA	With PDA	Without PDA
Photo-taking/sketching	56.6	36.4	7.4	42.9	77.7	40.0	2.9	34.8
Sensory experience	0	21.2	11.1	7.1	3.7	11.4	23.5	4.3
Further observation	3.3	6.1	18.5	7.1	0	8.6	17.6	4.3
Comparison	6.7	6.1	3.7	10.7	3.7	8.6	14.7	4.3
Question proposing	16.7	3.0	40.7	17.9	11.1	11.4	20.6	26.1
Final report	16.7	27.3	18.5	14.3	3.7	2.0	20.6	26.1
Total	100	100	100	100	100	100	100	100

that students with PDA were no better supported than students without PDA in handling trap-setting statements or figuring out questions.

Learning flow

The abovementioned learning flow was implemented in the two classes: with PDA and without PDA. Students were asked to choose from among four options in the questionnaire, identifying which of the six stages was: (i) the most helpful one, (ii) the most frustrating one, (iii) the most preferred one, and (iv) the most disliked one (see Table 4).

The results of the questionnaire were used to determine benefits, pitfalls and best practices of PDA-supported learning flow. We found these results intriguing when comparing the experiences of students who engaged in the same learning flow but with different supporting media. Students, both with and without PDA, liked their first stage the most. But when the photo-taking stage was followed by the sensory experience stage, none of the students with PDA showed any interest in the second stage. On the contrary, students without PDA for whom the sketching stage came first, found the sensory experience stage to be quite interesting. In order to prevent decreasing the interest of the sensory experience stage, it might be advisable to adjust the order of operations, placing the photo-taking stage after the sensory experience stage.

We also found that the without-PDA students' attitude towards sketching was quite complicated. Most students showed the strongest feelings in their rating of the sketching stage. Students' written comments: 'most helpful', 'most frustrating', 'like the most' and also 'like the least' provide us with their attitudes towards the sketching experience.

- Help me to know the flowers in much more detail.
- I do not like to sketch because I am not good at it. I quite often sketch it wrong. It looks ugly.
- The characteristics of this flower are not easy to sketch.
- It helps me to get a deeper impression of the flower.

Sketching takes place starting with a small fragment of the subject and then expanding it to encompass the entire thing, whereas photo taking can directly capture the whole structure at once. It is not easy to sketch the characteristics of a plant accurately, in detail, and concentrating on the sketching process itself places an additional cognition load on the student. The fact that 42.9% of students without PDA felt frustrated at this stage provides an ideal opportunity for at-hand photo-taking technology to facilitate experiential learning. Photo technology also enables learners to capture multiple aspects of plants in different stages of development thus providing a far more comprehensive view than could be found in standard library photos.

On the other hand, students with PDA, having been spared the difficult and onerous sketching process, found question proposing to be their most frustrating stage, which involved the use of sound recording as one kind of note-taking interface. We were surprised to discover that this frustration stemmed from many different sources. On the technical side, students reported that the interface was not particularly user-friendly but pedagogical problems also arose. Students pointed out the difficulties they faced in generating questions. Below are some written comments:

- I made many mistakes so that I had to redo it again and again.
- When I was recording, many classmates were around and spoke so loudly that I cannot hear what I said.
- It took me a lot of time to come up with a good question.
- My voice was recorded weirdly.

The students without PDA all shared the same simple problem: 'I cannot come up with any questions'.

Discussion

Our analysis shows that, as far as knowledge creation is concerned, students with PDA outperformed the students without PDA. However, we should not consider performance to be the only evidence to examine in assessing effectiveness of experiential learning. Rather, when considered from the perspective of progress through the six stages, we found that, after the photo-taking stage, students with PDA in general lost interest in engaged observation. We also found that they had great difficulty proposing questions in response to the four previous learning prompts. It seems that the photo-taking mechanism motivated students in the initial observation stage, but the findings suggest that the sketching process sustained motivation in the exploration stage in a more productive way. The experiment demonstrated that students perceived the function of the photo-taking mechanism plug-in PDA technology right at the beginning of experiential learning, however, it was not the technology itself but the interplay between technology and pedagogical practice that affords possibilities for better experiential learning.

These affordances can be seen most clearly when the learning flow and/or the supporting system are appropriate. For example, the steps may be ordered so that the photo-taking stage takes place after students engage in detailed observation so that they do not substitute mobile technologies for sensory experience thereby neglecting the authentic nature of experiential learning. The findings also suggest that the sound recording technology needs some adjustment to be applied effectively in the classroom environment where ambient noise is a problem.

Summing up, this study developed a mobile learning supported system using PDAs and a learning activity flow to support experiential learning. The various functionalities provided by the system guided students through the activity flow in a school garden with PDAs. Two classes participated in an experiment, one using PDAs and the other not using them. The results of the experiment revealed that those students using mobile technology to support their learning demonstrated an increased level of new knowledge creation, an enhanced awareness of learning in context and enriched conceptualization of knowledge through experience. Finally, a properly designed mobile technology system, together with the incorporation of pedagogical considerations into the design of the learning flow, did illustrate technology affordances through their interplay.

Three factors in this study are to be considered in future experiments. First, the motivational influence of new technologies may affect experiment results, though this effect may be of limited duration. A long-term experiment is therefore required to mitigate that motivational effect. Second, providing students with incorrect information at the comparison stage may cause a minority of students who were unable to carry out the exploration successfully to recall the incorrect information. Consequently, in this experiment the teacher presented the corrected statements and a brief conclusion after the final report stage in order to integrate students' knowledge. However, the effect of providing trap-setting statements as part of the experiment requires further exploration. Lastly, the study emphasized note taking on real characteristics of plants observed in a learning context and therefore comparisons between photo-taking and sketching were made. If focus is to be put on the accuracy of supplementary material, the use of standard library photos could be considered to replace sketching as an alternative to photo taking by students in the future.

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Appendix I

1. What shape is a leaf of African Touch-me-not?
   ① elliptical ② long ③ round ④ heart-shaped.
2. The height of an African Touch-me-not plant is about?
   ① 10–20 cm ② 30–50 cm ③ 80–100 cm ④ 100–200 cm.
3. In the following list, which is the most common color for African Touch-me-not flowers?
   ① yellow ② pink ③ brown ④ blue.
4. What shape is the leaf margin of the African Touch-me-not?
   ① saw-toothed ② smooth ③ deeply concave ④ acicular.
5. Which phyllotaxy does African Touch-me-not have?
   ① alternate ② opposite ③ verticillate.
6. Which category does an African Touch-me-not belong to?
   ① herbaceous plants ② woody plants ③ grass ④ fern.
7. The African Touch-me-not fruit is of which type?
   ① legume ② berry ③ bell-shaped ④ nut.
8. Which part of an African Touch-me-not grows hair?
   ① stem ② leaf ③ flower ④ none.