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A Decision-Tree-Oriented Guidance Mechanism for Conducting Nature Science Observation Activities in a Context-Aware Ubiquitous Learning Environment

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ABSTRACT

A context-aware ubiquitous learning environment is an authentic learning environment with personalized digital supports. While showing the potential of applying such a learning environment, researchers have also indicated the challenges of providing adaptive and dynamic support to individual students. In this paper, a decision-tree-oriented mechanism is developed for that purpose, enabling digital guidance for students to observe and classify real-world objects in the learning activities of natural science courses. To show the effectiveness of the innovative approach, a context-aware ubiquitous learning environment was implemented for the "butterfly and ecology" unit of a fourth-grade natural science course in Taiwan, and 42 students participated in the learning activity. From the surveys and interviews that were conducted to understand the functionalities of the system and the learning effectiveness for the students, the results show that the system had a positive impact on students' learning, especially on the affective domain, including participation, motivation, and interaction.

Keywords

Mobile learning, Ubiquitous learning, Context awareness, Decision tree, Ubiquitous computing

Introduction

In the past decades, various digitalized learning systems have been developed, with which adaptive learning has become possible for individual students (Hwang, 2003). Nevertheless, researchers have indicated that it is important to learn in an authentic environment as well as in a virtual world (Brown, Collins, & Duguid, 1989). Although traditional in-class learning is a method of authentic learning, it is difficult for the teacher to provide full personalized learning support to every student, especially when many students are gathered in the same class. Therefore, it is a challenging goal to develop a personal learning guidance mechanism that can provide students with guidance in a distributed learning environment.

The development of wireless networks and sensor technologies gives light to this goal, which allows the establishment of a learning environment with both authentic and virtual resources. With wireless networks, the students can interact with the digital learning system outside of the classroom and extend their learning experience to the authentic learning environment. With the addition of sensor technologies, the learning system can detect and record the learning behaviors of the students in the real world. Combining both technologies, the researchers attempt to realize context-aware ubiquitous learning (u-learning) (Chen, Chang, & Wang, 2008; Hwang, Tsai, & Yang, 2008; Hwang, Yang, Tsai, & Yang, 2009; Chu, Hwang, & Tsai, 2010; Hwang, Kuo, Yin, & Chuang, 2010).

However, this innovative learning environment may not be of benefit to most students if no effective assistance or guidance mechanism is installed. For this purpose, we have developed an innovative decision-tree-oriented mechanism, which enables digital guidance to individual students in the learning process. The system was implemented in a fourth-grade butterfly and ecology course in Taiwan. Surveys and interviews were conducted to understand the functionalities of the system and the learning effectiveness for the students. The results show that the system had a positive impact on students' learning, especially on the affective domain, including participation, motivation, and interaction.

Background and motivation

Lave (1991) indicated that schools are communities of practice with their own formal and informal codes of behavior, but this traditional learning cannot be regarded as situated since the curricular content is not used by the school community itself. Students find it difficult to apply knowledge learned from the textbooks outside of school because learning takes place within the culture of school life instead of within the culture where the domain knowledge is used (Brown et al., 1989). Students prefer "authentic activities" in which they can work with problems from the real world. Young (1993) summarized four critical tasks involved in instructional design for such situated learning:

1. Selection of the situation or set of situations that will afford the acquisition of knowledge that the teacher wishes each student to acquire (Shaw, Turvey, & Mace, 1982).
2. Provision of the necessary guidance for novices to operate within the complex realistic context, while still permitting experts to work within the same situation (Vygotsky, 1978; Bruner, 1986).
3. Provision of supports that enable teachers to track progress, assess information, and interact knowledgeably and collaboratively with individual students or cooperating groups of students (Collins, 1991).
4. Defining the role and nature of assessment and what it means to "assess" situated learning (Lave & Wenger, 1991).

In addition to learning in an authentic scenario, researchers have also indicated the importance of enabling students to access educational information flexibly, calmly, and seamlessly. In order to situate students in an authentic learning environment, which refers to direct experiences that take place within the context of practice, it is important to place the students in a series of designed lessons that combine both real and virtual learning environments (Minami, Morikawa, & Aoyama, 2004; Peng, Su, Chou, & Tsai, 2009). The advance of mobile technology has made this notion possible, while the advent of ubiquitous computing (u-computing) technologies has enabled students to learn in a more active and adaptive authentic learning environment (Hwang, Tsai, & Yang, 2008):

> Recently, scholars of e-learning have noticed the progress of wireless communication and sensor technologies; therefore, the research issues have progressed from web-based learning to mobile learning (Chu, Hwang, Huang, & Wu., 2008), and from mobile learning to context-aware ubiquitous learning (u-learning), in which the learning system can detect students' behaviors and guide them to learn in the real world with personalized support from the digital world (Hwang, Tseng, & Hwang, 2008; Yang, 2006).

To develop context-aware and seamlessly integrated Internet environments, a variety of new techniques and products concerning ubiquitous computing have been developed in recent years, such as handheld terminals, smart mobile phones, sensor network nodes, contactless smart cards, and radio frequency identification (RFID). The RFID system consists of a tag, which is made up of a microchip with an antenna, and an interrogator or reader with an antenna (Finkenzeller, 2000). The reader sends out electromagnetic waves, while the tag antenna is tuned to receive these waves. A passive RFID tag draws power from a field created by the reader and uses it to power the microchip's circuits. The chip then modulates the waves that the tag sends back to the reader, and the reader converts the new waves into digital data.

So far, several studies have been conducted to develop learning environments with u-computing technologies, such that the learning systems are able to sense the contextual information of the learners and provide personalized supports to them (Khedr, 2005; Hwang et al., 2008; Yang, 2006). Most of the previous studies concerning context-aware u-learning have been conducted on natural science courses (Rogers et al., 2005; Chu et al., 2008) or language training courses (Ogata & Yano, 2004; Joiner, Nethercott, Hull, & Reid, 2006), and have aimed to guide the students to observe real-world objects or to experience real-world contexts. For example, Ogata and Yano (2004) presented a u-learning system that has been used to guide students to learn Japanese in real-world situations. The systems can provide learners with appropriate expressions according to different contexts (e.g., occasions or locations) via mobile devices (e.g., personal digital assistants [PDAs]). Rogers and several other researchers (2005) integrated the learning experiences of indoor and outdoor activities by observation in a working environment. Learners are not only capable of getting data, voice, and images from the scene by observation, but also of gathering related information from learning activities via wireless networks. Only a few studies have attempted to apply this innovative approach to simple science experiments, such as computer hardware assembly (El-Bishouty, Ogata, & Yano, 2007).

Although this innovative approach enables students to learn in an authentic learning environment, the students are likely to get lost without proper guidance in a technology-enhanced learning environment (Lumpe & Butler, 2002;

Sharma & Hannafin, 2007; van Rooij, 2009). Most of the previous studies concerning context-aware ubiquitous learning have aimed at investigating the effects of providing "right content" (Ogata & Yano, 2004; Rogers et al., 2005; El-Bishouty et al., 2007; Chu et al., 2008) or "right function" (Yang, 2006; Joiner et al., 2006) in the right time at the right place, while the provision of conceptual supports based on the real-world context is usually omitted.

The study of Saye and Brush (2002) has shown that expert guidance may be embedded into the learning environment to give students conceptual and strategic road maps in the learning process. Hwang (2003) further emphasized the importance and challenge of recognizing learning status and providing personal guidance for individual students. Therefore, it is important to develop a guidance mechanism for contextualizing learning scenarios to support students to learn in the real world (Ge & Er, 2005).

To cope with this problem, this study aims to develop a guidance mechanism that can guide the learners to observe and identify objects in the real world with the help of wireless communication and mobile and sensor technologies. Students can reconstruct learning knowledge via interaction with the learning environment and observation of the real-world objects; in the meantime, the system will acquire the real-time situation of the students via the sensors, such that personalized learning supports can be provided for individual students.

Decision-tree-oriented guidance mechanism

In this study, a decision-tree-oriented guidance mechanism is proposed to develop a situated natural science learning environment. With this mechanism, the learning system can guide the students to learn in an authentic scenario by sensing their real-world behaviors.

Objectives and research settings

Natural science instruction is structural and procedural. Its knowledge is mostly definite with ultimate correct answers. Cognitive skills emphasize memory, comparison, distinction, and analysis. Students need in-time guidance to construct systematic knowledge. In this study, the authentic learning environment of the natural science course is a butterfly and ecology garden located in an elementary school. The garden consists of 18 areas of foodstuff plants for butterflies and supports 24 kinds of butterflies. The "Butterfly and Ecology" course is the school-based curriculum of the chosen elementary school. The complete teaching cycle lasted for one semester, two hours per week, for 18 weeks.

The evaluation of the research can be divided into three stages. First, the performance of the u-learning system was reviewed by nine elementary teachers, who had experience teaching natural science courses, in order to evaluate the correctness and effectiveness of the u-learning system. Second, the learning outcome was assessed by the field trial of the students for the purpose of detecting students' learning motivation and perceptions of the implementation issues. Questionnaires were distributed to 42 students. Moreover, the teaching effects indicated by the questionnaire results were calculated by a paired t test (the learning experiences before and after the learning activities) to show the impact on the affective domain, including participation, motivation, and interaction. Lastly, the two teachers who developed the learning content and led the field teaching for this learning activity were interviewed to probe their use of the digital system and its effect on the teaching process. All surveys used a five-point Likert-scale, the responses to which were coded as 1 = strongly disagree through to 5 = strongly agree.

Critical-feature-finding algorithm

To guide the students to find the misrecognized features of the plants during the situated learning process, we propose a decision-tree-oriented guidance mechanism, the critical-feature-finding algorithm (CFFA). "Critical features" are the key features for classifying or comparing a set of target learning objects. By identifying the critical features, students can significantly improve their observation and classification ability. The learning guidance procedure of CFFA is give as follows:

Stage 1: Construct decision tree.

Stage 2: Locate the common feature of the correct answer, x, and the answer of the student, y (assume that the student failed to correctly answer the question). We have

A = critical feature (x, y) = the nearest common attribute of x and y in the decision tree.

Stage 3: Trace the value of A for answers x and y. Display the two values and relevant image files to the student.

Stage 4: Repeat the test with the same question. That is, the student is guided to observe the critical feature of the plant again, and then answer the same question. If the student still fails to answer the question, go to Step 1.

Stage 5: Conduct the test with the next question.

To construct quality decision trees, we employed the ID3 algorithm, which is originally a machine-learning algorithm (Quinlan, 1983) for generating decision rules from a set of training examples. ID3 uses information theory to select features that give the greatest information gain (or decrease of entropy), so that well-structured decision trees can be constructed from the training examples. That is, in a decision tree constructed by the ID3 algorithm, the more significant features are placed at the locations that are closer to the root of the tree, implying that the features with more classification power will play more important roles in guiding the students to learn to classify the target learning objects. Such a learning guidance strategy meets the basic notation for teaching classification knowledge in science courses (i.e., showing the most significant features to the students). Therefore, ID3 is an appropriate approach to developing the decision-tree-oriented guidance mechanism for teaching classification knowledge in a u-learning environment.

Entropy is defined as $-p\log_2 p$, where probability p is a determined description from the frequency of occurrence. In the training process, each training example is represented by a list of features, and the class memberships of each training example must be known. The idea is to examine training examples and find the minimum number of original features that suffice in determining class membership.

Assume that N is the total number of learning examples, and N_i the number of examples that belong to class i for i = 1, 2,…, C. The information entropy for the problem consisting of N examples can be represented as entropy (I) = $\sum_{i=1}^{C} -\frac{N_i}{N}\log_2\left(\frac{N_i}{N}\right)$, which represents the distribution of the examples from different classes. A large entropy (I) means that those different classes contain an almost equal number of examples, while a small (close to 0) entropy (I) indicates that almost all of the examples belong to the same class (Quinlan, 1983; Cios & Liu, 1992).

Illustrative example

In the following, an illustrative example is given to explain how ID3 is used to classify a set of butterfly host plants, including how information entropy is calculated and how the decision tree is generated. Assume that C_1, $C_2 \ldots C_8$ represent eight butterfly host plants: Aristolochia heterophylla Hemsl, Aristolochia zollingeriana Miq, Aristolochia kaempferi Willd, Aristolochia cucurbitifolia, Ricinus communis L, Citrus poonensis Hort, Melicope semecarpifolia, and Tylophor ovata Hook. Each training example is described by three features:

1. Angiosperm, with possible values “woody vine,” “shrub,” or “tree”
2. Phyllotaxy, with possible values “alternate” or “opposite”
3. Shape of leaf, with possible values “oblong & elliptical,” “elliptical,” “cordate,” “palmate,” “palmate & divided” or “ovate.”

Assume that there are eight training examples as summarized in Table 1. The information in all eight examples is measured by the entropy function:

Entropy (I) = $-p_{C1} \times \log_2 \times p_{C1} - p_{Cc2} \times \log_2 \times p_{C2} - p_{C3} \times \log_2 \times p_{C3} \ldots - p_{C8} \times \log_2 \times p_{C8}$

= $(-(1/8) \times \log_2(1/8)) \times 8 = 3$

To generate decision rules that correctly classify training examples, ID3 performs a feature test by first selecting a feature, and then dividing examples into subclasses using the selected feature. Next, it calculates the information entropy to determine how significant the feature is. For instance, when a test on the feature “angiosperm” is made, the eight examples are divided into three subclasses, that is, “woody vine,” “tree,” and “shrub.” The sum of the information entropy for each subclass can then be calculated. By subtracting the information entropies of these subclasses from that of original training example set, ID3 derives the information gain of the feature “angiosperm.” In a similar way, the information gains for testing “phyllotaxy” and “shape of leaf” can be obtained, respectively.

Table 1. Training example

Features			Class
Angiosperm	Phyllotaxy	Shape of leaf	
woody vine	alternate	oblong & elliptical	C_1
woody vine	alternate	cordate	C_2
woody vine	alternate	elliptical	C_3
woody Vine	alternate	palmate	C_4
shrub	opposite	palmate & divided	C_5
tree	alternate	ovate	C_6
tree	opposite	elliptical	C_7
tree	opposite	oblong & elliptical	C_8

As ID3 searches for a feature that gives the greatest information gain, the maximum information gain is obtained by comparing the information gains of the features “angiosperm,” “phyllotaxy,” and “shape of leaf.” The other features will be tested and the decision tree will be extended until all leaf nodes contain examples that belong to a single class, as shown in Figure 1.

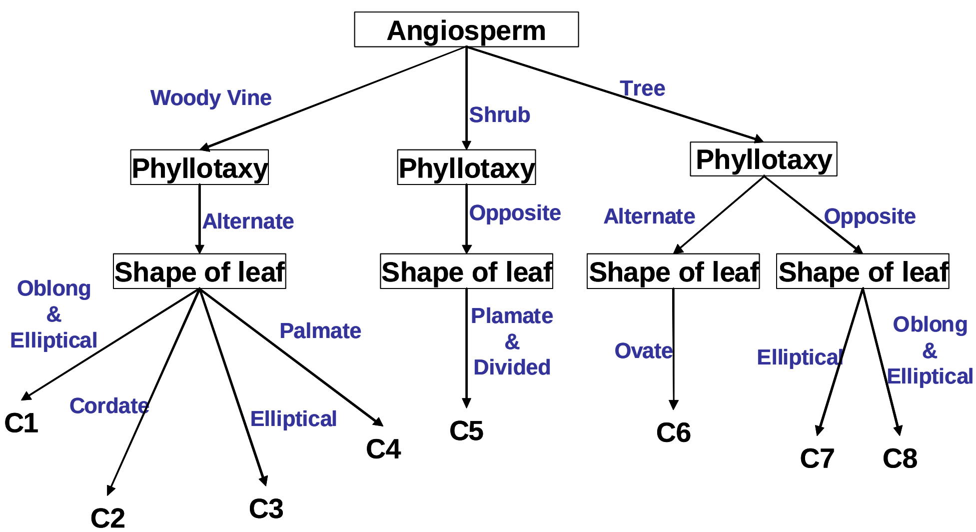

Figure 1. Illustrative example of a decision tree

Assume that the student has failed to recognize the target learning object C_8, and treated it as C_6. From Figure 1, the nearest common attribute of C_6 and C_8 is “phyllotaxy”; that is, “phyllotaxy” is the to-be-enhanced critical feature for the student. Therefore, the learning system will try to guide the student to observe the “phyllotaxy” features of both C_6 and C_8 (i.e., “alternate” and “opposite,” respectively), and then ask the student to identify the target learning object again.

Development of the context-aware u-learning environment

Figure 2 shows the notation of the context-aware u-learning environment, which is a butterfly garden with each butterfly host plant labeled with an RFID tag. Each student has a mobile device equipped with an RFID reader. Moreover, wireless communication is provided, so that the mobile device can communicate with a computer server.

As the students move in the learning area, the system can detect their locations by reading and analyzing the data from the nearest RFID tag. Therefore, the learning system can interact with the students, including guiding them to observe target objects (e.g., plants or butterflies), presenting supplemental materials to them, and asking some questions to evaluate their performance in the real world, as shown in Figure 3.

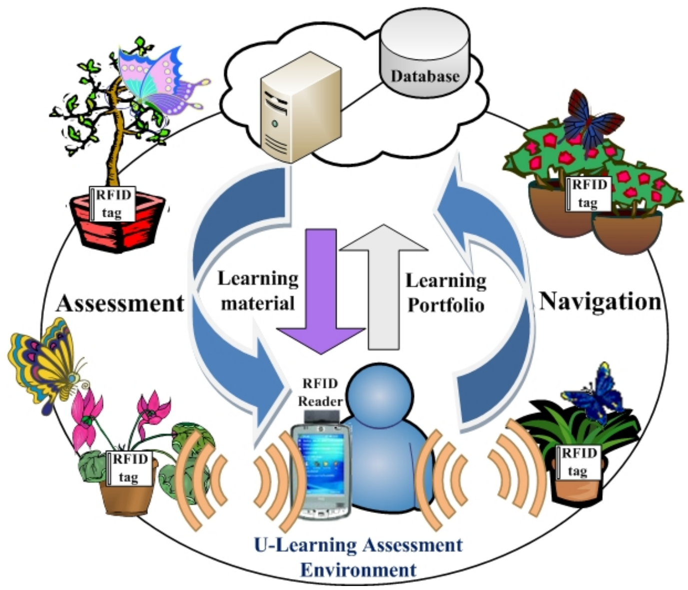

Figure 2. System architecture

Figure 3. The butterfly ecology garden

Figure 4. Illustrative example of guiding the student to observe the critical feature of the plant

Figure 4 shows the user interface for guiding the student to a plant and asking the student to identify it. If the student fails to correctly identify the plant, the u-learning system will compare the correct answer and the student's answer to find the critical feature based on the decision tree generated by applying the ID3 method. If the student fails to correctly answer the question for the second time, the u-learning system shows the student the correct answer and detailed information of the plant.

Research results

In the survey of the first stage concerning the u-learning system performance, the participants were asked to fill in a questionnaire about the system functionalities and interface designs (as shown in Table 2). Note that this survey focused mainly on the use of PDA, not on the ID3 algorithm.

Table 2. Statistical results of the questionnaire from nine teachers

No.	Items	5	4	3	2	1	Mean
1.	This teaching model can elevate learning motivation.	4	5	0	0	0	4.44
2.	This teaching model can elevate learning effectiveness.	3	4	2	0	0	4.11
3.	This teaching model can help students to learn about butterfly features and biological developments.	3	6	0	0	0	4.33
4.	The system has high feasibility.	2	5	2	0	0	4.00
5.	The system can help teachers to reduce their teaching burden.	1	7	0	1	0	3.89
6.	I would recommend this system to my colleagues.	1	7	1	0	0	4.00
7.	The use of icons and text in this system is coherent.	2	7	0	0	0	4.22
8.	I can easily find the functions in the system.	0	6	2	1	0	3.56
9.	To switch between pages in the system is easy.	0	7	2	0	0	3.78
10.	The interface design including text color, size, and icons is easy to identify.	5	3	1	0	0	4.44
11.	The messages provided by the system are brief and concise.	2	7	0	0	0	4.22
12.	The overall manipulation of the system is easy.	3	5	1	0	0	4.22

Most of the teachers think that the system can promote students' motivation (Item 1) and learning effectiveness (Item 2), and agree that, with the digital support, students can better learn about butterflies' physical features and biological transformation (Item 3). Therefore, they believe that this system can be more widely used in natural science learning. However, in terms of the teaching burden, the teachers take two very distinct perspectives (Item 5). Some teachers think that the system does not help in reducing the teaching load because they have to spend more time teaching students about the use of the technology as well as solving their problems in the field. On the other hand, some teachers think that the system provides individual support and guidance so they will not have to run everywhere to answer students' questions. They mostly conclude that they might suggest that their peers use this system, but it depends on how stable the technology is when it is implemented (Item 6).

Concerning the system interface, the coherence between icons and texts is consistent (Item 7). Users can easily find the functions they need because the layout is in accordance with users' habits (Item 8). Therefore, the ease of finding functions and switching between pages on the interface is not scored as high (Item 9), which means that the interface design needs to be improved. Other than that, the messages provided by the system are brief and concise (Item 11), and the overall manipulation is acceptable to most teachers (Item 12).

From the students' responses in the second stage, the results show that the digital system and PDAs can help students in their learning during the butterfly course (as shown in Table 3).

Students' learning motivation is not significantly raised by this course (Item 1 vs. Items 8, 9, and 19) because they were originally interested in butterflies. However, no matter whether students had used a PDA before or not (Item 2), they think using a PDA to learn is not only interesting (Item 9) but also helpful (Items 20–25). When using a PDA, their learning motivation is high (Item 25) because it is convenient (Item 12) and easy (Item 13). Students like to observe butterflies, not because they like the appearance of butterflies (Item 6), nature (Item 7), or general knowledge (Item 8). Rather, it is seen that students' interest in participating in this course comes from the PDA's guidance (Items 23, 24, and 25).

Table 3. Statistical results of the questionnaire from 42 students

No.	Before class	5	4	3	2	1	Mean
1.	I would go to the butterfly garden to do observation by myself.	25	14	3	0	0	4.52
2.	I have used a PDA before.	2	10	5	13	12	2.45
3.	I have used a digital camera to take photos of butterflies before.	19	18	5	0	0	4.33
4.	I have searched for butterfly information on the web.	5	15	9	7	6	3.14
5.	The teacher would use supplementary tools such as photos and graphics to teach about butterflies.	23	16	3	0	0	4.48
No.	**During class**						
6.	I like to observe butterflies because their appearance is appealing.	7	20	11	4	0	3.71
7.	I like to observe butterflies because I like nature.	10	20	9	3	0	3.88
8.	I like to observe butterflies because I can learn more about them.	9	16	14	3	0	3.74
9.	The PDA's guidance when observing butterflies is more interesting than the teacher's classes.	27	12	3	0	0	4.57
10.	I tried to use the PDA to search for related information during the observation.	12	14	8	8	0	3.71
11.	I like learning with the PDA's guidance.	15	12	13	2	0	3.95
12.	I think using a PDA to learn is convenient.	23	19	0	0	0	4.55
13.	I think using a PDA to learn is easy.	24	18	0	0	0	4.57
14.	I am more willing to learn and discuss with peers when using a PDA.	16	15	8	3	0	4.05
No.	**After class**						
15.	Being able to use a PDA is one of the benefits of this class.	16	19	7	0	0	4.21
16.	Being able to use a PDA for learning is one of the benefits of this class.	18	22	2	0	0	4.38
17.	I know more about the butterfly garden after taking the class.	15	22	5	0	0	4.24
18.	I am more concerned about the butterflies around me after taking the class.	19	18	5	0	0	4.33
19.	I would spend more time after class to learn about butterflies.	12	18	7	5	0	3.88
20.	I think using a PDA to learn is more interesting than before.	24	18	0	0	0	4.57
21.	I am glad to use a PDA in the butterfly learning process.	25	17	0	0	0	4.60
22.	I think a PDA, which can provide one-to-one teaching, can help me to learn better than the teacher's explanations.	20	22	0	0	0	4.48
23.	I have gained a lot from using a PDA to learn.	23	15	4	0	0	4.45
24.	Learning with a PDA makes me feel more comfortable.	17	20	5	0	0	4.29
25.	Learning with a PDA can enhance my learning motivation.	20	20	2	0	0	4.43
26.	I would recommend the PDA learning system to others.	17	16	6	3	0	4.12

In terms of functions, students do not use PDAs to browse the web (Item 10) as often as they use them for learning guidance (Item 11). The possibilities include that the decision-tree-oriented scaffolding system has already embedded sufficient expert knowledge to guide their learning, and that the PDA interface is too small to allow comfortable searching for external information.

From reading the statistics and analyzing the data from the students' interviews, we found that, generally speaking, students like to use PDAs to learn and think it is more interactive than teachers' explanations (Item 22). Nevertheless, students would have to be sure of the stability of the system before they would recommend it to their peers (Item 26). This corresponds to the teachers' interview in the first stage. It is understandable that technology feasibility, stability, and sustainability are the most essential concerns in terms of its integration into teaching and learning.

The students' responses to the questionnaire items before and after participating in the u-learning activity led to some interesting results, which are presented in Tables 4 and 5. As shown in Table 4, we found that most students did not have prior experience with using a PDA (mean = 2.45 for Item 2), but after the u-learning activity, they stated, "Learning with a PDA makes me feel more comfortable" (mean = 4.29 for Item 24); moreover, the students felt that "Learning with a PDA can enhance [their] learning motivation" (mean = 4.43 for Item 25). The lack of previous experience using a PDA did not affect the learning motivation of the students.

Table 4. Descriptive statistics for select pre- and post-class questionnaire items

No.	Questionnaire items	Mean	*n*	*SD*
Before class				
2.	I have used a PDA before.	2.45	42	1.27
After class				
24.	Learning with a PDA makes me feel more comfortable.	4.29	42	0.67
25.	Learning with a PDA can enhance my learning motivation.	4.43	42	0.59

Table 5 shows that most students did not have very high willingness to search for butterfly information on the Internet before participating in this learning activity (mean = 3.14 for Item 4). After experiencing the learning process, the feedback to the questionnaire item "I would spend more time after class learning about butterflies after taking the class" shows that their willingness to learn about butterflies has been improved (mean = 3.88 for Item 19). Such an improvement may be due to the use of this innovative approach to learning (mean = 4.50 for Item 23), which has significantly promoted learning motivation (mean = 4.43 for Item 25).

Table 5. Descriptive statistics for select pre-class and post-class questionnaire items

No.	Questionnaire items	Mean	*n*	*SD*
Before class				
4.	I have searched for butterfly information on the web before.	3.14	42	1.26
After class				
19.	I would spend more time after class to learn about butterflies after taking the class.	3.88	42	0.97
23.	I have gained a lot from using a PDA to learn.	4.50	42	0.63
25.	Learning with a PDA can enhance my learning motivation.	4.43	42	0.59

In the third stage, the two teachers who conducted the field teaching gave more explanations about the use of the system and its integration into teaching. Both of them have worked in elementary schools for a long time, five and eight years respectively. This shows that they are both experienced teachers in teaching and guiding students through the butterfly course. They both stated that teaching situated learning courses takes much more time and effort to prepare because context-aware facilities and ubiquitous learning supports must be well arranged to ensure students' individual learning. Courses in natural science, especially those that involve living creatures, require the use of multi-media and various teaching methods and skills. For structured knowledge, such as types and characteristics of butterflies, teachers' explanations are best for providing well-rounded information. To increase live applications, students need to explore on their own in the field so that they can generate personal experiences. Observing butterflies and plants helps to increase students' affective response. However, for the ubiquitous learning process, students need more personal guidance from both the digital system and teachers so that the varied individual questions can be answered. Things like butterflies' biological transformation are difficult to observe, so instead, they can be shown through multimedia presentations.

Training students to become butterfly garden guides takes three to six months depending on their learning performance. Consequently, to enable students to reach this high level of learning, personal support from digital devices can be very helpful. Using PDAs and a digital system, teachers and students do not need to run between the garden and the classroom in order to get necessary information. As an alternative, learning resources are handy in digital forms when students are in the field. The one-to-one guidance plays a more effective role in the process of teaching. To make this even more sustainable, the teachers indicated that if the system can document students' learning process, including their speed, direction, questions asked and answered, as well as their learning results, the teachers will get more information about the students' progress and needs. If diagnostic intervention is needed, the log can provide sufficient information for doing that.

In addition, both of the teachers believed that the system and teaching model can be applicable to many other subjects, such as language and arts, science, social science, and even physical education, as long as there is a need to conduct situated learning and a need to provide individual support.

Finally, to evaluate the effectiveness of the innovative approach (i.e., PDA learning with the decision tree guidance mechanism), both of the teachers suggested testing the ability of individual students in identifying the 18 plants in the garden. Each student needed to write down the name and the features of a plant when he/she was led to it. For each plant, if the answer was completely correct, the score was 1.0; if the answer was partially correct, the score was 0.5. A pre-test and a post-test were performed before and after conducting the u-learning activity. Table 6 presents the *t*-test results, which show significant improvements after the students participated in the learning activity ($p < 0.001$).

Table 6. Mean comparison between pre-test and post-test results using a paired-sample *t* test

	N	Mean	Standard deviation	Mean difference	*t*
Pre-test	42	8.14	3.32	−4.905	−26.813***
Post-test	42	13.05	2.79		

$^{***}p < 0.001$

Conclusions

In this study, a decision-tree-oriented scaffolding approach is proposed for conducting natural science observation activities. We aim to improve students' ability to classify and observe learning objects in the real world. To guide the students to learn, a well-organized and easy-to-follow knowledge structure for the subject content is required. Therefore, representing knowledge with a decision tree is much more suitable than other approaches such as neural networks, Bayesian networks, or rule-based engines. To demonstrate the benefits of the innovative approach, a series of experiments was conducted on the "butterfly and ecology" unit of a fourth-grade natural science course of an elementary school over a period of 18 weeks.

From the survey and interviews of the teachers who experienced the innovative learning environment, we saw that this environment was highly accepted by most of the teachers. They agreed that, with the decision-tree-oriented scaffolding in the authentic learning environment, students can better learn about butterflies' physical features and biological transformation; therefore, it was suggested that more learning activities of other science courses that aim to enable students to construct procedural and structural knowledge can be conducted in this test field. On the other hand, the teachers also indicated that teaching burdens might be increased by the students' insufficient knowledge of how to use the new technology. Fortunately, mobile devices are becoming more and more popular, and such a concern will gradually reduce.

In addition, from the survey of the students who took the course, we observed that the decision-tree-oriented guidance mechanism integrated in the course seems to be effective in enhancing students' learning motivation, especially with new tools and innovative teaching methods. The statistical data show that, no matter whether students have used a PDA before or not, they think using one to learn is not only interesting, but also helpful, which has clarified the concern of the teachers about the possible teaching burden caused by the students' insufficient knowledge of how to use the new technology. The students also indicated that their learning motivation is high thanks to the use of PDAs, including their convenience and ease of use, and guidance with the decision-tree-oriented scaffolding. Therefore, it is worth conducting long-term and large-scale experiments in the future to observe the learning effectiveness of such an innovative approach.

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References

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

Bruner, J. (1986). *Actual minds, possible worlds.* Cambridge, MA: Harvard University Press.

Chen, G. D., Chang, C. K., & Wang, C. Y. (2008). Ubiquitous learning website: Scaffold learners by mobile devices with information-aware techniques. *Computers & Education*, *50*(1), 77–79.

Chu, H. C., Hwang, G. J., Huang, S. X., & Wu, T. T., (2008). A knowledge engineering approach to developing e-libraries for mobile learning. *The Electronic Library, 26*(3), 303–317.

Chu, H. C., Hwang, G. J., & Tsai, C. C. (2010). A knowledge engineering approach to developing mindtools for context-aware ubiquitous learning. *Computers & Education*, 54(1), 289–297.

Cios, K. J., & Liu N. (1992). A machine learning method for generation of a neural network architecture: A continuous ID3 algorithm. *IEEE Transaction on Neural Networks, 3*(2), 280–291.

Collins, A. (1991). The role of computer technology in restructuring schools. In K. Shingold., & M. S. Tucker (Eds.), *Restructuring for learning with technology*. New York, NY: National Center on Education and the Economy.

El-Bishouty, M. M., Ogata, H., & Yano, Y. (2007). PERKAM: Personalized knowledge awareness map for computer supported ubiquitous learning. *Educational Technology & Society, 10*(3), 122–134.

Finkenzeller, K. (2000). *RFID Handbook: Radio-Frequency Identification Fundamentals and Applications* (R. Waddington, Trans.). Hoboken, NJ: John Wiley & Sons Press.

Ge, X., & Er, N. (2005). An online support system to scaffold real-world problem solving. *Interactive Learning Environments, 13*(3), 139–157.

Hwang, G. J. (2003). A concept map model for developing intelligent tutoring systems. *Computers & Education, 40*(3), 217–235.

Hwang, G. J., Tsai, C. C., & Yang, Stephen. J. H. (2008). Criteria, strategies and research issues of context-aware ubiquitous learning. *Educational Technology & Society*, *11*(2), 81–91.

Hwang, G. J., Tseng, J. C. R., & Hwang, G. H. (2008). Diagnosing student learning problems based on historical assessment records. *Innovations in Education and Teaching International*, *45*(1), 77–89.

Hwang, G. J., Yang, T. C., Tsai, C. C., & Yang, Stephen. J. H. (2009). A context-aware ubiquitous learning environment for conducting complex experimental procedures. *Computers & Education*. 53, 402–413.

Hwang, G. J., Kuo, F. R., Yin, P. Y., & Chuang, K. H. (2010). A heuristic algorithm for planning personalized learning paths for context-aware ubiquitous learning. *Computers & Education*, 54, 404-415.

Joiner, R., Nethercott, J., Hull, R., & Reid, J. (2006). Designing educational experiences using ubiquitous technology. *Computers in Human Behavior, 22*(1), 67–76.

Khedr, M. (2005, March). *A semantic-based, context-aware approach for service-oriented infrastructures.* Paper presented at the 2nd IFIP International Conference on Wireless and Optical Communications Networks (WOCN 2005), Dubai, United Arab Emirates.

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

Lave, J., (1991). Situating learning in communities of practice. In L. B. Resnick., J. M. Levine., & S. D. Teasley (Eds.), *Perspectives on Socially Shared Cognition* (pp. 63–82). Washington, DC: American Psychological Association.

Lumpe, A. T., & Butler, K. (2002). The information seeking strategies of high school science students. *Research in Science Education, 32*(4), 549–566.

Minami, M., Morikawa, H., & Aoyama, T. (2004). The design of naming-based service composition system for ubiquitous computing applications. *Proceedings of the 2004 Symposium on Applications and the Internet-Workshops (SAINT 2004 Workshops)* (pp. 304–312). Washington, DC: IEEE Computer Society Press.

Ogata, H., & Yano, Y. (2004, March). *Context-aware support for computer-supported ubiquitous learning.* Paper presented at the 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education, JhongLi, Taiwan.

Peng, H. Y., Su, Y. J., Chou, C., & Tsai, C. C. (2009). Ubiquitous knowledge construction: Mobile learning re-defined and a conceptual framework. *Innovations in Education and Teaching International, 46*(2), 171–183.

Quinlan, J. R. (1983). Learning efficient classification procedures and their application to chess end-games. In R. S. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine Learning: An artificial intelligence approach* (pp. 463–482). Palo Alto, CA: Morgan Kaufmann.

Rogers, Y., Price, S., Randell, C., Fraser, D. S., Weal, M., & Fitzpatrick, G. (2005). Ubi-learning: Integrating indoor and outdoor learning experiences. *Communications of the ACM, 48*(1), 55–59.

van Rooij, S. W., (2009). Scaffolding project-based learning with the project management body of knowledge (PMBOK®). *Computers & Education, 52*(1), 210–219.

Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development, 50*(3), 77–96.

Sharma, P., & Hannafin, M. J., (2007). Scaffolding in technology-enhanced learning environments. *Interactive Learning Environments, 15*(1), 27–46.

Shaw, R., Turvey, M. T., & Mace, W. (1982). Ecological psychology: The consequence of a commitment to realism. In W. B. Weimer., & D. S. Palermo (Eds.), *Cognition and the symbolic processes* (pp. 159–226). Hillsdale, NJ: Lawrence Erlbaum.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological process.* Cambridge, MA: Harvard University Press.

Yang, Stephen. J. H. (2006). Context aware ubiquitous learning environments for peer-to-peer collaborative learning. *Educational Technology & Society, 9* (1), 188–201.

Young, M. F. (1993). Instructional design for situated learning. *Educational Technology Research and Development, 43*(1), 43–58.