Computers & Education 55 (2010) 1618–1627

Contents lists available at ScienceDirect

Computers & Education

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

# A two-tier test approach to developing location-aware mobile learning systems for natural science courses

Hui-Chun Chu [a], Gwo-Jen Hwang [b,*], Chin-Chung Tsai [b], Judy C.R. Tseng [c]

[a] Department of Computer Science and Information Management, Soochow University, 56, Sec. 1, Guiyang St., Taipei City 100, Taiwan
[b] Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, 43, Sec.4, Keelung Road, Taipei 106, Taiwan
[c] Department of Computer Science and Information Engineering, Chung-Hua University, Taiwan, 707, Sec. 2, Wufu Road, Hsinchu City 300, Taiwan

ARTICLE INFO

*Article history:*
Received 29 March 2010
Received in revised form
2 July 2010
Accepted 5 July 2010

*Keywords:*
Mobile learning
Ubiquitous learning
Two-tier test
Context awareness

ABSTRACT

The advancement of wireless and mobile technologies has enabled students to learn in an environment that combines learning resources from both the real world and the digital world. Although such an approach has been recognized as being innovative and important, several problems have been revealed in practical learning activities. One major problem is owing to the lack of proper learning strategies or tools for assisting the students to acquire knowledge in such a complex learning scenario. Students might feel excited or engaged when using the mobile devices to learn in the real context; nevertheless, their learning achievements could be disappointing. To deal with this problem, this study presents a mobile learning system that employs Radio Frequency Identification (RFID) technology to detect and examine real-world learning behaviors of students. This study also utilizes each student's responses from a two-tier test (i.e., multiple-choice questions in a two-level format) to provide personalized learning guidance (called two-tier test guiding, $T^3G$). The experimental results from a natural science course of an elementary school show that this innovative approach is able to improve the learning achievements of students as well as enhance their learning motivation.



## 1. Introduction

In the past decade, various computer-assisted or web-based learning systems have been developed to provide a more adaptive learning environment with plenty of learning resources (Huang, Lin, & Cheng, 2009; Tseng, Chu, Hwang, & Tsai, 2008; Yeh, Chen, Hung, & Hwang, 2010). Much attention has been focused on new learning strategies with appropriate software tools and environments (Hwang, Tseng, & Hwang, 2008; Lan, Sung, & Chang, 2009; Panjaburee, Hwang, Triampo, & Shih, 2010), such as Computer scaffolding (Ge & Land, 2004; Williams van Rooij, 2009), the activity-theoretical approach (Liaw, Huang, & Chen, 2007), and Mobile Computer-Supported Intentional Learning Environments (Nussbaum et al., 2009). These learning strategies have been applied, together with Internet access, in classroom teaching.

Several studies have demonstrated the benefits of computer- and network-based learning (e.g. Leng et al., 2009; Pena-Shaffa & Nichollsb, 2004); nevertheless, experienced educators have emphasized more the importance and necessity of "authentic activities" in which students are able to work with problems from the real world (Herrington & Oliver, 2000; Hwang, Chu, Shih, Huang, & Tsai, 2010; Lave, 1991). Recent popularity of wireless communication and mobile technologies has provided the opportunity to situate students in authentic learning environments with access to the digital resources (Hwang, Tsai, & Yang, 2008). Individual students, by using a mobile device (e.g. portable computers or cellular phones) with wireless communications, are able to learn in real-world situations with support or instructions from the computer system. Moreover, the advancement of sensing technology has enabled the learning system to detect and record the students' learning behaviors in the real world. Learning behavior emphasizes the crucial link that represents the interaction of the individual with contextual and social factors. Researchers have indicated that the link occurs when positive relationships are established between the learners and themselves (e.g. more learning motivation), the learners and others (e.g. teachers and peers), and the learners and the learning

* Corresponding author. Tel.: +886 9153 96558; fax: +886 6301 7001.
*E-mail addresses:* carolhcchu@gmail.com (H.-C. Chu), gjhwang.academic@gmail.com (G.-J. Hwang), cctsai@mail.ntust.edu.tw (C.-C. Tsai), judycrt@chu.edu.tw (J.C.R. Tseng).

0360-1315/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compedu.2010.07.004

environment (e.g. learning systems and learning materials) (Powell & Tod, 2004). The sensing technology-enhanced mobile learning model not only provides learners with an alternative to deal with problems in the real-world context, but also enables the learning system to interact with the learners more actively (Ogata & Yano, 2004; Yang, Okamoto, & Tseng, 2008); consequently, researchers have called it context-aware ubiquitous learning (Hwang et al., 2008).

Without proper support, the new learning scenario might become too complex for the students to understand and use. Educators have indicated that "technologies should not support learning by attempting to instruct the learners, but rather should be used as knowledge construction tools that students learn *with*, not *from*" (Jonassen, Carr, & Yueh, 1998, p. 1). Computers, among the existing technologies, have been recognized as being a potential tool to support learning and instruction, such that the learners act as designers, and the computers function as tools for interpreting and organizing their personal knowledge (Chu, Hwang, & Tsai, 2010; Jonassen, 1999; Jonassen et al., 1998). Hence, it has become an important and challenging issue to develop personalized learning guidance systems to assist learners to interpret and organize their personal knowledge for mobile and ubiquitous learning.

In this paper, a mobile learning system that employs RFID (Radio Frequency Identification) technology to detect the learning behaviors of students and provide learning guidance in the real world is presented. Moreover, a two-tier test approach for providing personalized guidance in mobile learning activities is proposed. A learning activity on a natural science course has been conducted to evaluate the effectiveness of the innovative approach in comparison with the tour-based mobile learning approach.

## 2. Relevant research

Early studies of mobile learning focused on building learning systems to "supplement" students to learn in authentic learning environments. For example, Chen, Kao, and Sheu (2003) constructed an outdoor mobile-learning activity about bird watching by using handheld devices to show learning sheets and supplementary materials. Rogers et al. (2005) employed mobile and wireless communication to enable children to observe and collect data in woodlands. In their study, mobile devices were utilized as a tool for recording observations.

In recent years, researchers have further attempted to use sensing technologies to provide more effective learning supports. For example, Chu, Hwang, Huang, and Wu (2008) developed a mobile learning system for training students to identify the characteristics of the plants on a school campus. The learning system was able to guide the students to learn in the real-world environment by detecting their learning behaviors with sensing technology. Hwang, Yang, Tsai, and Yang (2009) developed a context-aware ubiquitous learning system with mobile, wireless communication and sensing technologies for guiding inexperienced researchers to practice single-crystal X-ray diffraction operations. Such a location-aware mobile learning approach has extended the scope of experiential learning, location-based learning and outdoor learning, which situate students in real-world learning scenarios (Bamberger & Tal, 2007; Orion, Hofstein, Tamir, & Giddings, 1997), from pure in-field learning to a new learning scenario that combines both the real-world and digital-world learning resources (Kolb, 1984; Rogers et al., 2005; Vogel, Spikol, Kurti, & Milrad, 2010). To effectively and efficiently assist students in interpreting and organizing their personal knowledge, it is necessary to develop new tools and strategies by taking both the real-world and the digital-world factors into consideration, such that the students can gain knowledge and learning experiences with personalized supports from the learning systems (Chen et al., 2003; Chu et al., 2010; Hwang, Chu, et al., 2010; Hwang, Kuo, Yin, Chuang, 2010; Nussbaum et al., 2009; Shih, Chu, Hwang, & Kinshuk, in press); therefore, it has become an important and challenging issue to develop location-aware mobile learning strategies.

Researchers have pointed out several criteria for instructional design in such situated learning environments, including the selection of situations that would afford the particular knowledge to be learned (Chen et al., 2003), the provision of the necessary "scaffolding" for novices to operate in the complex realistic context and for experts to work in the same situation (Hwang et al., 2009; Williams van Rooij, 2009), the provision of teacher supports for tracking the learning progress of students (Chen, Hwang, Yang, Chen, & Huang, 2009; Leng et al., 2009; Ogata & Yano, 2004; Peng et al., 2009), and the development of strategies for assessing the effectiveness of situated learning (Paige & Daley, 2009).

Although effective tools or environments have potential in engaging individual learners in constructive, higher-order, critical thinking about the subjects they are studying (Jonassen, 1999; Schiaffino, Garcia, & Amandi, 2008), it is difficult to design suitable learning strategies for supporting and guiding learners in the environments that combine real-world and digital-world learning resources. Therefore, it has become an important and challenging issue to develop effective and easy-to-follow learning guidance models for location-aware mobile learning.

Researchers have indicated the importance of assessing the learning status or prior knowledge of individual students before providing learning guidance (Hwang, 2003; Hwang et al., 2008; Tseng et al., 2008). Among the existing testing strategies, two-tier tests have been recognized as being an efficient and effective way to investigate students' prior knowledge or misconceptions by many researchers, especially in science education (Odom & Barrow, 1995; Treagust, 1988; Tsai, 2003). A two-tier test is a two-level multiple-choice question. The first tier assesses students' descriptive or factual knowledge about the phenomenon to be assessed. The second-tier probes the students' reasons for their choice made in the first tier, trying to explore their in-depth explanations of the factual knowledge. The use of two-tier tests allows teachers or researchers to not only understand students' possible incorrect ideas, but also to assess the reasoning or in-depth understanding behind these ideas. In this way, researchers can acquire more detailed information about students' existing or prior knowledge. In recent years, some researchers (Tsai & Chou, 2002) have developed networked two-tier test systems, in which only one tier of a test item per screen is presented. Such a system facilitates assessment of existing knowledge of a larger sample of students in a more efficient and relatively straightforward manner. As the two-tier test is in a multiple-choice format, it is much simpler for researchers or educators to interpret students' responses (Tsai & Chou, 2002); moreover, it is very suitable to be implemented in mobile learning devices with limited screen size, as only one tier needs to be displayed per screen. Therefore, in this study, a location-aware mobile learning system based on a *revised* two-tier test approach is proposed to provide personalized learning guidance in the authentic learning environment.

## 3. A location-aware mobile learning environment with a two-tier test approach

In this study, the authentic learning environment is an elementary school garden consisting of 12 areas of plants as the target objects. Each target plant is labeled with an RFID tag, while each student holds a mobile device equipped with an RFID reader. In addition, wireless communication is provided to enable communication between the mobile device and the computer server that executes the learning system. The students who participate in the learning activity are asked to observe and recognize the features of the target plants. As they move around in the authentic learning environment, the learning system can detect the location of individual students by reading and analyzing the data from the nearest RFID tag. Accordingly, the learning system is able to actively provide personalized guidance or hints to individual students by interacting with them via the mobile device.

### 3.1. Two-tier test guiding mechanism

With the help of the sensing technology, the mobile learning system can detect the location of individual students, and guide them to find the location of the target plants. Once a student arrives at a target plant, a series of questions is presented to guide them to observe and recognize the features of that plant. Moreover, the learning system guides individual students in further learning based on their responses to the questions; that is, a two-tier test guiding mechanism was employed to evaluate the domain knowledge of the students and guide them to learn based on the evaluation results, as shown in Fig. 1. The details of the Two-Tier Test Guiding ($T^3G$) Mechanism are given as follows:

*Step 1*: Guide the student to find the location of the target plant.
*Step 2*: Conduct first-tier observations of the target plant:
Present the first-tier question concerning a feature of the target plant to guide the student to observe that feature.
Step 2.1: If the student fails to recognize the feature of that plant by giving an incorrect description:
Step 2.1.1 Guide the student to a comparative plant to show the difference ` that particular feature.
Step 2.1.2: Ask the student to answer the question again. If the student fails to correctly recognize the feature again, present the corresponding supplementary materials to the student.
Step 2.2: If the student correctly recognizes the feature of the plant:
Step 2.2.1: Present the second-tier question that asks the student an advanced or in-depth conception related to the answer.
Step 2.2.2: If the student fails to correctly answer the second-tier question, present some hints or supplementary materials to the student and go to Step 2.2.1.

*Step 3*: Repeat Step 2 until the student has correctly recognized all of the features of the plant and has been confirmed as being well equipped with the relevant knowledge.

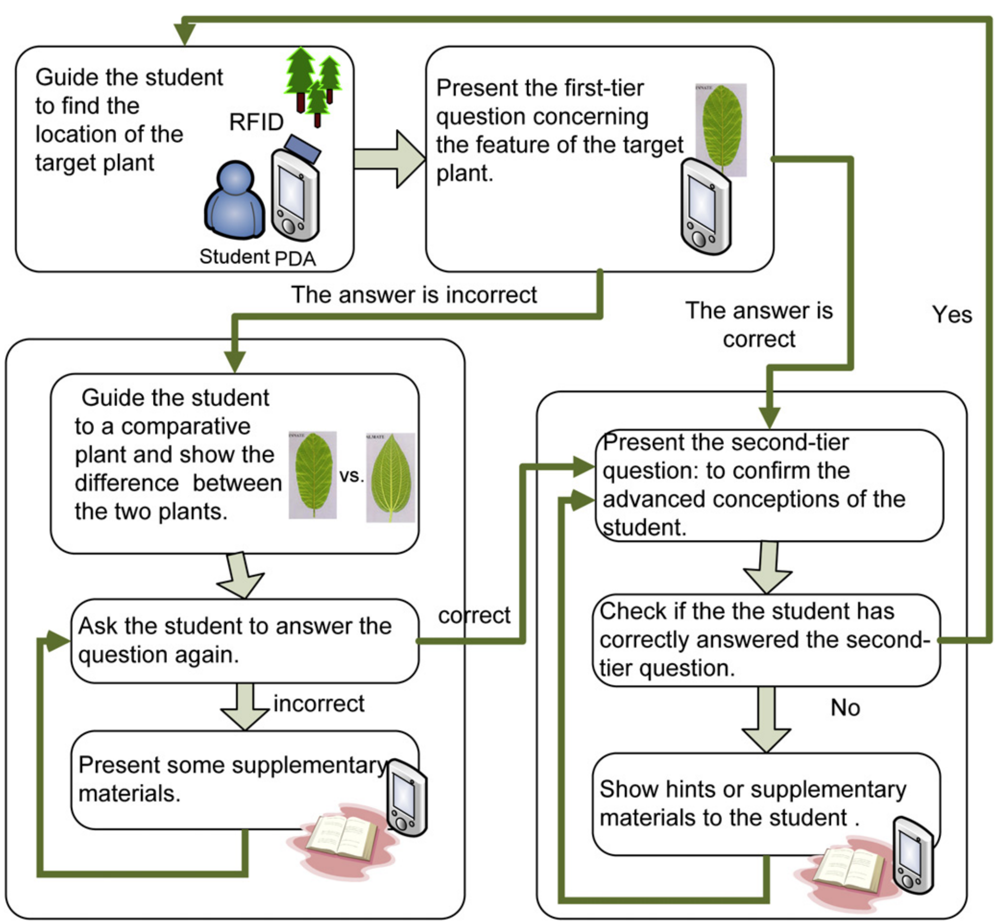


**Fig. 1.** Mobile learning guidance mechanism based on the two-tier test approach.

*Step 4*: Guide the student to visit the next target plant and repeat Steps 2–5 until all of the target plants are observed.

For example, the student observes the plant (target object) "Palimara Alstonia" and describes its "Leaf arrangement" as "Opposite". By comparing the student's answer with the correct answer given by the teacher (i.e., "The leaf vein has many branches"), the learning system finds that the student's answer is incorrect. Consequently, the learning system tries to find a comparative plant whose "Leaf-arrangement" is "Opposite" from the database (i.e., to find a plant that matches the incorrect feature described by the student). Assume that another plant "Blue sky vine" on the school campus has this feature, that is, its "Leaf arrangement" is "Opposite". In that case, the student is guided to observe "Blue sky vine" and compare its "Leaf arrangement" with that of "Palimara Alstonia".

On the other hand, if the student has correctly answered the question (i.e., the leaf-arrangement of "Palimara Alstonia" is "Whorled"), the learning system will ask the student to answer the second-tier question. In this illustrative example, the second-tier question could be *Leaves are arranged on a stem in a definite fixed order, called phyllotaxy, for different species of plants. Which one of the following descriptions is correct for the leaf arrangement "Whorled".*

(1) *Leaf attachments are singular at nodes, and leaves alternate direction, to a greater or lesser degree, along the stem.*
(2) *Leaf attachments are paired at each node; decussate if, as typical, each successive pair is rotated 90° progressing along the stem; or distichous if not rotated, but two-ranked (in the same geometric flat-plane).*
(3) *Three or more leaves attach at each point or node on the stem. As with opposite leaves, successive whorls may or may not be decussate, rotated by half the angle between the leaves in the whorl (i.e., successive whorls of three rotated 60°, whorls of four rotated 45°, etc). Opposite leaves may appear whorled near the tip of the stem.*

In this illustrative example, the correct answer is "3". If the student's answer is incorrect, the learning system would provide corresponding learning materials of plants to the student, and then ask the student to answer the question again.

Thus, in this learning system, the first-tier questions are designed to guide individual students to cultivate careful observation skills, while the second-tier questions aim to evaluate if the students are equipped with correct conceptions to explain what they have observed.

### 3.2. Mobile learning system for natural science course

Based on this innovative approach, the Two-Tier Test Guiding ($T^3G$) has been developed to assist the students to observe and classify learning objects in the real world. $T^3G$ is able to detect the location of individual students and provide them with adaptive supports via the use of PDA's (Personal Digital Assistants) equipped with RFID and wireless communication equipment.

Fig. 2(a) shows an illustrative example of $T^3G$ in guiding the students to find the target object "Liquidambar" on the campus. The student is then asked to observe the "leaf point" of "Liquidambar" and answer the question generated from the enhanced repertory grid model, as shown in Fig. 2(b).

If the student fails to correctly identify the plant feature, the $T^3G$ system will try to guide him/her to observe another plant which exhibits the incorrect answer, and compare the difference between the features of the two target plants. For example, in Fig. 3, if an incorrect answer "Round with a blunt tip" is given by the student for the "leaf shape" of "Liquidambar", the learning system will guide the student to find the

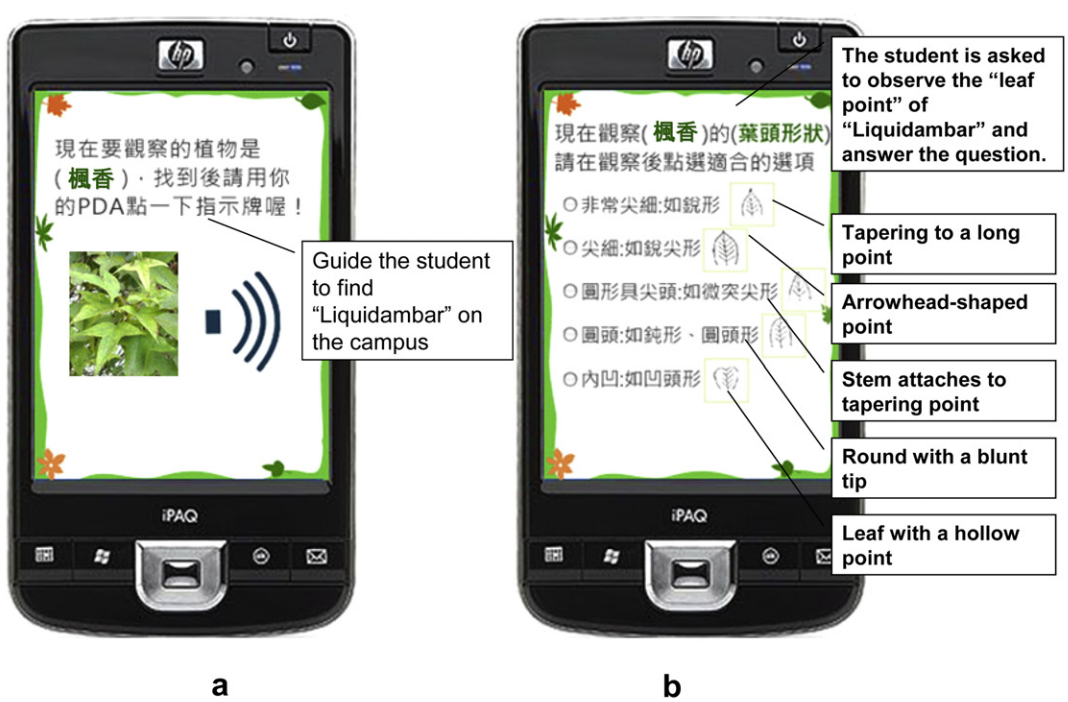


**Fig. 2.** Example of guiding the student to find and observe the target plant.


**Fig. 3.** Example of guiding the student to the plant with the “incorrect feature”.

plant “Golden Leaves” that really has a leaf point that is “Round with a blunt tip” and compare it with the leaf point of the original target “Liquidambar”. To assist the student in easily finding the plant “Golden Leaves”, the T$^3$G system shows a campus map which marks the plant “Golden Leaves” and the student’s location.

When the student is close to the plant “Golden Leaves”, the T$^3$G system will guide him/her to observe and compare the leaf shapes of “Golden Leaves” and “Liquidambar”, as shown in Fig. 4(a). The student is then asked to walk back to the target plant “Liquidambar”, and answer the question concerning “the leaf shape of Liquidambar” again, as shown in Fig. 4(b).

## 4. Experiment design

To evaluate the effectiveness of the innovative approach, an experiment was conducted on a natural science course of an elementary school located in southern Taiwan. The experiment aimed to investigate whether the students who learned with T$^3$G attained better results

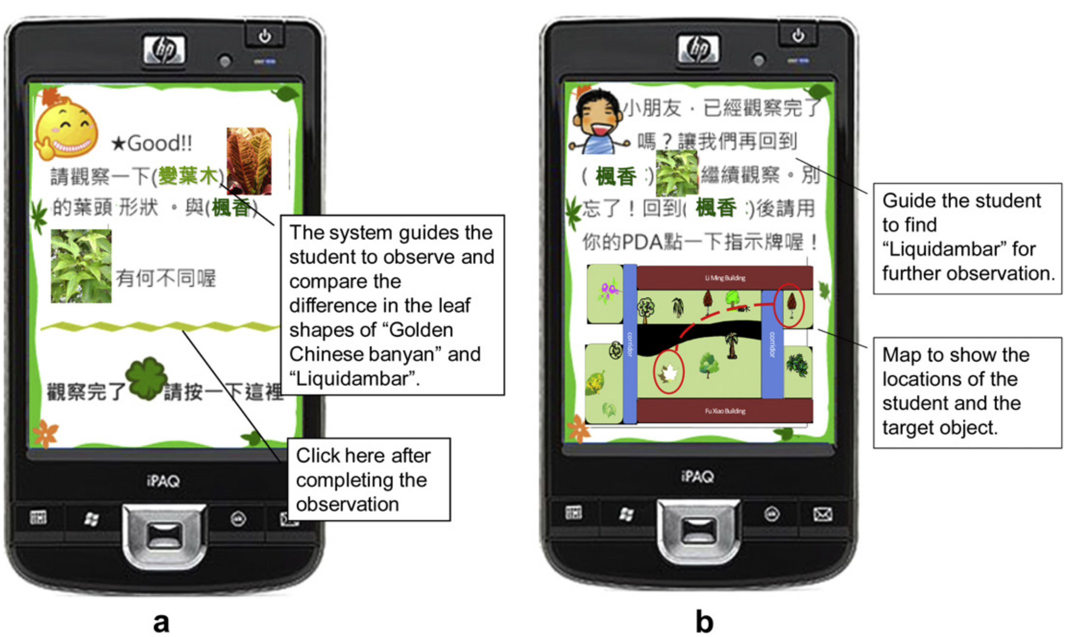


**Fig. 4.** Interface for guiding the student to compare the leaf shapes of “Golden Leaves” and “Liquidambar”.

and had more positive perceptions than those who learned in a "pure" (tour-based) u-learning environment. In the following subsections, the design and analysis of the results of the experiment are given in detail.

### 4.1. Participants

The participants of this study were 57 fifth-grade students taught by the same teacher in an elementary school. Their average age was 11. After receiving the fundamental plant knowledge in a natural science course, they were divided into a control group ($n = 29$) and an experimental group ($n = 28$).

### 4.2. Learning activity design

Fig. 5 shows the procedure of the experiment. In the first stage (four weeks), the teacher was guided to provide the classification knowledge of the target plants. This experiment contained 13 learning objects (plants on the school campus), namely "Spindle palm", "Golden dewdrop", "Variegated leaf croton", "Golden Leaves", "Star Cluster", "Bread-fruit Tree", "Liquidambar", "Common garcinia", "Golden Bamboo", "Odour-bark cinnamon", "Blue sky vine", "Devil's lvy", and "Golden dewdrop".

In the second stage, after receiving the fundamental knowledge of the plants in the natural science course (about 50 min), all of the students were asked to take a pre-test. They spent nearly 40 min answering the test items, which aimed to evaluate their basic knowledge about the plants on the campus.

After taking the pre-test, the students in the experimental group were arranged to observe and compare the features of 13 plants on the campus using the u-learning system with the T$^3$G approach. On the other hand, the students in the control group were guided to observe the plants via the common tour-based u-learning approach; that is, they learned with PDA's equipped with an RFID reader, with which the learning system can detect the location of individual students, guide them to the target plants, and provide them with relevant learning materials as soon as they approach a target plant. This stage took about 160 min for each group. After conducting the learning activity, the students were asked to take a post-test and answer a post-questionnaire (45 min).

### 4.3. Instruments

To evaluate the learning effectiveness of the students, a pre- and a post-test were developed; in addition, to collect the students' perceptions about the ubiquitous learning activity and their attitudes toward learning science, a perception questionnaire survey (see Appendix A) and an attitude questionnaire survey (see Appendix B) were administered to all students as well.

The pre-test aimed to confirm that the two groups of students had the equivalent basic knowledge required for taking this particular subject unit. It was composed of 25 fill-in-the-blank items with a full score of 100. The post-test consisted of two types of test items: 15 multiple-choice items and 8 short essay items with a full score of 100. It focused on evaluating the students' knowledge about comparing and classifying the plants based on their leaf features. Both the pre- and post-test were designed by the teacher who taught the Natural Science course to the two groups of students. The tests were also evaluated by other science educators for expert validity.

The perception and the attitude questionnaires were designed to collect the students' perceptions about the mobile learning activity on the campus and their attitudes toward learning science after participating in the experiment. They originated from a questionnaire developed by Chu et al. (2010), with a reliability coefficient of 0.91.

The perception questionnaire used in this study consisted of 19 six-point Likert-scale items where 1 represented "strongly disagree" and 6 represented "strongly agree". It included three scales concerning students' perceptions of the ubiquitous learning activity, including "experiences about using the PDA", "feelings about the mobile learning system" and "degree of satisfaction with the learning approach". The attitude questionnaire consisted of 7 six-point Likert-scale items. Both the questionnaires were reviewed by three experts to ensure content validity. The Cronbach's alpha value for each scale of the perception questionnaire was 0.67, 0.88 and 0.91 respectively, and for the attitude questionnaire it was 0.89. These values indicated adequate reliability of assessing students' perceptions of the learning activity and their attitudes toward learning science.

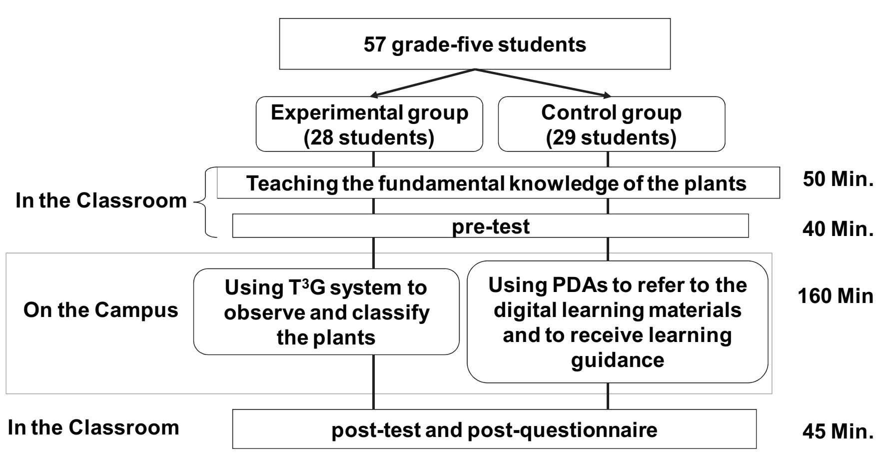


**Fig. 5.** Procedure of the context-aware u-learning activity for comparing the T$^3$G and the tour-based u-learning approaches.

**Table 1**
Descriptive data and ANCOVA result for the post-test scores.

| | | N | Mean | S.D. | Adjusted mean | Std. error. | *F value* | *d* |
|---|---|---|---|---|---|---|---|---|
| Post-test | Experimental group | 28 | 56.21 | 11.74 | 54.97 | 2.16 | 11.26*** | 0.93 |
| | Control group | 29 | 44.31 | 13.68 | 43.78 | 2.11 | | |

***$p < 0.001$.

**Table 2**
Independent *t*-test on the perceptions and attitudes of the experimental and control group students.

| | | Experimental Group (Mean, S.D.) | Control Group (Mean, S.D.) | *t* | *d* |
|---|---|---|---|---|---|
| Perception of participating in the u-learning activity | Scale 1: experiences of using the PDA (Items 1–3) | 5.29/1.17 | 5.28/1.13 | 0.03 | |
| | Scale 2: feelings about the mobile learning system (Items 4–10) | 5.29/0.95 | 4.89/1.00 | 1.53 | |
| | Scale 3: degree of satisfaction with the learning approach (Items 11–19) | 5.58/0.48 | 4.97/0.95 | 3.02** | 0.80 |
| Attitude toward learning science | | 5.33/0.79 | 4.53/1.02 | 3.27** | 0.87 |

**$p < 0.01$.

## 5. Results

### 5.1. Learning achievements of the students

An independent *t*-test was used to analyze the pre-test. The mean and standard deviation of the pre-test were 72.5 and 11.59 for the experimental group, and 71.14 and 14.56 for the control group. As the *p*-value (Significant level) $> 0.05$ and $t = 0.46$, it can be inferred that these two groups did not significantly differ prior to the experiment. That is, the two groups of students had statistically equivalent abilities before taking the subject unit.

Table 1 shows the ANCOVA results of the post-test using the pre-test as a covariate; the original means and standard deviations are also presented. From the post-test scores, it was found that the students in the experimental group had significantly better achievements than those in the control group ($F = 11.26$, $p < 0.001$). Moreover, the effect size *d* was computed to measure the strength of the treatment between the two groups (Cohen, 1988). In Cohen's definition, "$d = 0.2$" indicates "small" effect size; "$d = 0.5$" means "medium" effect size, and "$d = 0.8$" means "large" effect size. In Table 1, the Cohen's *d* value of 0.93 indicates a large effect size, suggesting a great help from the $T^3G$ approach. This result indicates that learning with the $T^3G$ approach-assisted u-learning significantly benefited the students more than learning in a "pure" u-learning environment in terms of knowledge acquisition.

### 5.2. Questionnaire survey

Table 2 shows the statistical results of the post-questionnaire scales, including the means. It was found that the students in the experimental group had a more positive perception of participating in the u-learning activity based on their satisfaction with the learning approach ($t = 3.02$, $p < 0.01$); moreover, they also had a more significantly favorable attitude toward learning science than those in the control group ($t = 3.27$, $p < 0.01$). Furthermore, the Cohen's *d* of the Scale 3 items "students' satisfaction with the learning approach" and "students' attitude toward learning science" were 0.80 and 0.87, respectively, suggesting a large effect size. The $T^3G$-assisted u-learning led

**Table 3**
Independent *t*-values on selected perception items for the experimental group and control group students.

| | | Experimental group (mean, S.D.) | Control group (mean, S.D.) | *t* |
|---|---|---|---|---|
| Scale 2: Feelings about the learning system | Q10. I have endeavored to follow the learning guidance given by the system during the learning process. | 5.32/0.98 | 4.55/1.30 | 2.52* |
| Scale 3: Satisfaction with the learning approach | Q12. I have endeavored to observe the differences between the target learning objects in this learning activity. | 5.43/0.84 | 4.66/1.26 | 2.72** |
| | Q14. Learning with the PDA system is more challenging and interesting than learning with the traditional approach. | 5.82/0.39 | 5.17/1.17 | 2.80** |
| | Q15. I had new findings or knowledge about the target learning objects owing to the use of this PDA system to learn in the authentic environment. | 5.64/0.68 | 5.17/1.04 | 2.02* |
| | Q17. The guidance provided by this PDA system is helpful to me in learning how to identify the features of the target learning objects. | 5.75/0.52 | 5.07/1.16 | 2.84** |
| | Q18. The guidance provided by this PDA system is helpful to me in observing the differences within the target learning objects. | 5.68/0.55 | 5.00/1.39 | 2.41* |
| | Q19. When using this PDA system, I learned how to observe the target learning objects from new perspectives. | 5.54/0.74 | 4.90/1.26 | 2.32* |

*$p < 0.05$, **$p < 0.01$.

**Table 4**
Independent $t$-test on the "attitude toward learning science" items of the experimental group and control group students.

| | Experimental group (Mean, S.D.) | Control group (Mean, S.D.) | $t$ |
|---|---|---|---|
| Q1. After participating in the learning activity, I am more interested in observing and exploring the features of natural objects. | 5.18/0.98 | 3.93/1.56 | 3.60*** |
| Q3. I care more about those learning objects on the school campus after participating in this learning activity. | 5.25/0.89 | 4.07/1.67 | 3.32** |
| Q6. I will actively try to observe the features of other natural objects. | 5.29/0.85 | 4.31/1.37 | 3.22** |
| Q7. This innovative way of learning makes me want to know more about plants. | 5.39/0.83 | 4.38/1.27 | 3.56*** |

**$p < 0.01$, ***$p < 0.001$.

to a considerable improvement in students' learning satisfaction and attitudes toward learning science, when compared to the "pure" u-learning approach.

An item-by-item analysis was conducted to further examine which items showed differences between the two groups of students. Some findings with individual item descriptions are given in Table 3. For the Scale 2 item "Feelings about the mobile learning system", the students in the experimental group were significantly more willing to follow the guidance of the learning system than those in the control group (Item 10). That is, the students were apparently more willing to follow the instructions given by the learning system developed with the $T^3G$ approach.

For the Scale 3 item "Degree of satisfaction with the learning approach", all of the participants indicated that learning with the $T^3G$ system made them endeavor more to observe the differences between the target objects (Item 12). Moreover, they felt that the u-learning activity with the $T^3G$ approach was more challenging and interesting than the traditional learning activities (Item 14) and they could make new findings about the learning targets (Item 15). More importantly, in comparison with the "pure" u-learning approach, the students in the experimental group revealed significantly more positive perceptions of the helpfulness of the learning guidance provided by the PDA system in identifying the features of the target objects (Item 17) and observing the differences between the objects (Item 18). The statistical results also showed that with the $T^3G$ approach, the students in the experimental group had significantly better perceived ability in learning how to observe the target objects from new perspectives (Item 19).

Table 4 shows the $t$-test result for the "attitude toward learning science" items. It was found that the students in the experimental group revealed significantly more favorable attitudes toward observing and actively exploring the features of natural objects than those in the control group after participating in the learning activity (Items 1, 3 and 6); moreover, they cared more about those learning objects after participating in the learning activity (Item 7).

## 6. Conclusions

Recently, mobile and wireless communication technologies have become popular among research groups. In mobile learning, the students are situated in a real-world environment with supports from the digital world. Thanks to the novelty and pleasure of using mobile devices outside the classroom, such learning activities frequently receive promising feedback from the students (Chen et al., 2003; Hwang et al., 2009). Therefore, most researchers and school teachers regard such equipment as a convenient channel that enables students to access digital resources from the Internet. Nevertheless, the issue of developing new strategies or tools to improve the learning achievements of students in such learning environments has attracted relatively little attention.

In this paper, we present a sensing technology-enhanced mobile learning system, which employs an enhanced two-tier test approach to guide students to observe and recognize target learning objects in the real world. The developed system has been applied to a learning activity of a natural science course in an elementary school. The results of the experiment demonstrate that this innovative approach promotes learning attitude, and improves the learning achievements of individual students as well. This finding is quite different from those of previous studies (Chu et al., 2008; El-Bishouty, Ogata, & Yano, 2007; Peng, Chou, & Chang, 2008), which mainly investigated the correlation among the learning attitude, the learning behaviors and the acceptance of the technology in mobile and ubiquitous learning.

To sum up, the use of the $T^3G$ system to support this u-learning activity not only improved the learning achievements of the students, but also promoted the students' interest and gave them more incentives to take Natural Science courses. Most of the students in the experimental group showed their willingness to participate in such learning activities in the future, and would like to recommend this learning system to other classmates. Furthermore, the questionnaire survey also showed that the $T^3G$ approach was able to provide more interesting and challenging learning scenarios to the students, so that their attitude toward learning science was significantly improved, which was even a challenging task for those experienced teachers. Therefore, it is worth trying to apply this innovative approach to the learning activities of other courses in the future. In addition, it is also interesting and important to investigate how to improve the quality of the mobile learning system so that the learners will benefit more (Chilcott & Hadfield, 2009).

## Acknowledgements

This study is supported in part by the National Science Council of Taiwan under contract numbers NSC 96-2628-S-024-001-MY3 and NSC 98-2631-S-024-001.

## Appendix A. Questionnaire items for perception of participating in the u-learning activity.

| | |
|---|---|
| | Scale 1: Experiences of using the PDA |
| 1. | The learning system is easy to use. |
| 2. | It only took me a short time to fully know how to use the PDA after participating in this learning activity. |
| 3. | The PDA system always displayed adequate web pages to me quickly. |
| | Scale 2: Feelings about the mobile learning system |
| 4. | I like to learn with the PDA system since it provides personalized learning guidance and allows me to have my own schedule. |
| 5. | I would like to know if the innovative approach can be applied to other courses to improve my learning performance. |
| 6. | I would like to learn with the PDA system in the future. |
| 7. | I would recommend this learning system to others. |
| 8. | The use of PDAs makes this learning activity more interesting. |
| 9. | The guidance provided by the PDA system is easy to understand and follow. |
| 10. | I have endeavored to follow the learning guidance given by the system during the learning process. |
| | Scale 3: Satisfaction with the learning approach |
| 11. | The mission of this learning activity makes me better understand how to identify and classify the features of the target learning objects. |
| 12. | I have endeavored to observe the differences between the target learning objects in this learning activity. |
| 13. | The mission of this learning activity was not easy to complete, but it was easy to understand the way of learning. |
| 14. | Learning with the PDA system is more challenging and interesting than learning with the traditional approach. |
| 15. | I had new findings or knowledge about the target learning objects owing to the use of this PDA system to learn in the authentic environment. |
| 16. | I have tried new ways or thinking styles to learn owing to the use of this mobile learning system. |
| 17. | The guidance provided by this PDA system is helpful to me in learning how to identify the features of the target learning objects |
| 18. | The guidance provided by this PDA system is helpful to me in observing the differences within the target learning objects. |
| 19. | When using this PDA system, I learned how to observe the target learning objects from new perspectives. |

## Appendix B. Attitude toward learning science.

| | |
|---|---|
| 1. | After participating in the learning activity, I am more interested in observing and exploring the features of natural objects. |
| 2. | After participating in the learning activity, I am more confident in recognizing the features between the target learning objects. |
| 3. | I am more interested in taking the Natural Science course after participating in this learning activity. |
| 4. | I care more about those learning objects on the school campus after participating in this learning activity. |
| 5 | I prefer to take the Natural Science course via observing the objects in the real-world learning environment. |
| 6 | I will actively try to observe the features of other natural objects. |
| 7. | This innovative way of learning makes me want to know more about plants. |

## References


Bamberger, Y., & Tal, T. (2007). Learning in a personal context: levels of choice in a free choice learning environment in science and natural history museums. *Science Education, 91*(1), 75–95.

Chen, C. H., Hwang, G. J., Yang, T. C., Chen, S. H., & Huang, S. Y. (2009). Analysis of a ubiquitous performance support system for teachers. *Innovations in Education and Teaching International, 46*(4), 1–13.

Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning, 19*(1), 347–359.

Chilcott, M., & Hadfield, T. (2009). *Mobile blended learning for the workplace study*. Newport: Centre for Excellence in Learning and Teaching Journal, Institute of Digital Learning, University of Wales.

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.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

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

Ge, X., & Land, S. M. (2004). A conceptual framework for scaffolding ill-structured problem-solving processes-using question prompts and peer interactions. *Educational Technology Research & Development, 52*(2), 5–22.

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research & Development, 48*(3), 23–48.

Huang, Y.-M., Lin, Y.-T., & Cheng, S.-C. (2009). An adaptive testing system for supporting versatile educational assessment. *Computers & Education, 52*(1), 53–67.

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

Hwang, G. J., Chu, H. C., Shih, J. L., Huang, S. H., & Tsai, C. C. (2010). A decision-tree-oriented guidance mechanism for conducting nature science observation activities in a context-aware ubiquitous learning environment. *Educational Technology & Society, 13*(2), 53–64.

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.

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

Hwang, G. J., Tseng, Judy. 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*(2), 402–413.

Jonassen, D. H. (1999). *Computers as mindtools for schools, engaging critical thinking*. Englewood Cliffs, NJ: Prentice-Hall.

Jonassen, D. H., Carr, C., & Yueh, H. P. (1998). Computers as mindtools for engaging learners in critical thinking. *TechTrends, 43*(2), 24–32.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. NJ: Prentice-Hall.

Lan, Y. J., Sung, Y. T., & Chang, K. E. (2009). Let us read together: development and evaluation of a computer-assisted reciprocal early English reading system. *Computers & Education, 53*(4), 1188–1198.

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.

Leng, B. A.de, Dolmans, D. H. J. M., Jöbsis, R., Muijtjens, A. M. M., & Vleuten, C. P. M.van der (2009). Exploration of an e-learning model to foster critical thinking on basic science concepts during work placements. *Computers & Education, 53*(1), 1–13.

Liaw, S. S., Huang, H. M., & Chen, G. D. (2007). An activity-theoretical approach to investigate learners' factors toward e-learning systems. *Computers in Human Behavior, 23*, 1906–1920.

Nussbaum, M., Alvarez, C., McFarlane, A., Gomez, F., Claro, S., & Radovic, D. (2009). Technology as small group face-to-face collaborative scaffolding. *Computers & Education, 52* (1), 147–153.

Odom, A. L., & Barrow, L. H. (1995). The development and application of a two-tiered diagnostic test measuring college biology students' understanding of diffusion and osmosis following a course of instruction. *Journal of Research in Science Teaching, 32*, 45–61.
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.
Orion, N., Hofstein, A., Tamir, P., & Giddings, G. J. (1997). Development and validation of an instrument for assessing the learning environment of outdoor science activities. *Science Education, 81*(2), 161–171.
Paige, J. B., & Daley, B. J. (2009). Situated cognition: a learning framework to support and guide high-fidelity simulation. *Clinical Simulation in Nursing, 5*(3), 97–103.
Panjaburee, P., Hwang, G. J., Triampo, W., & Shih, B. Y. (2010). A multi-expert approach for developing testing and diagnostic systems based on the concept effect model. *Computers & Education, 55*, 527–540.
Pena-Shaffa, J. B., & Nichollsb, C. (2004). Analyzing student interactions and meaning construction in computer bulletin board discussions. *Computers & Education, 42*(3), 243–265.
Peng, H., Chou, C., & Chang, C.-Y. (2008). From virtual environments to physical environments: exploring interactivity in ubiquitous-learning systems. *Journal of Educational Technology & Society, 11*(2), 54–66.
Peng, H. Y., Chuang, P. Y., Hwang, G. J., Chu, H. C., Wu, T. T., & Huang, S. X. (2009). Ubiquitous performance-support system as mindtool: a case study of instructional decision making and learning assistant. *Educational Technology & Society, 12*(1), 107–120.
Powell, S., & Tod, J. (2004). *A systematic review of how theories explain learning behaviour in school contexts. Research evidence in education library*. London: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London.
Rogers, Y., Price, S., Stanton Fraser, D., Randell, C., Weal, M., & Fitzpatrick, G. (2005). Ubi-learning integrates indoor and outdoor experiences. *Communications of the ACM, 48*(1), 55–59, Shih, J.L.
Schiaffino, S., Garcia, P., & Amandi, A. (2008). Teacher: providing personalized assistance to e-learning students. *Computers & Education, 51*(4), 1744–1754.
Shih, J. L., Chu, H. C., Hwang, G. J., & Kinshuk. An investigation of attitudes of students and teachers about participating in a context-aware ubiquitous learning activity. *British Journal of Educational Technology*, in press, doi:10.1111/j.1467-8535.2009.01020.x
Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students misconceptions in science. *International Journal of Science Education, 10*(2), 159–169.
Tsai, C. C. (2003). Using a conflict map as an instructional tool to change student alternative conceptions in simple series electric-circuits. *International Journal of Science Education, 25*(3), 307–327.
Tsai, C. C., & Chou, C. (2002). Diagnosing students' alternative conceptions in science through a networked two-tier test system. *Journal of Computer Assisted Learning, 18*, 157–165.
Tseng, Judy C. R., Chu, H. C., Hwang, G. J., & Tsai, C. C. (2008). Development of an adaptive learning system with two sources of personalization information. *Computers & Education, 51*(2), 776–786.
Vogel, B., Spikol, D., Kurti, A., & Milrad, M. (2010). Integrating mobile, web and sensory technologies to support inquiry-based science learning, Paper presented at the 6th IEEE International Conference on Wireless, Mobile, and Ubiquitous Technologies in Education, Kaohsiung, Taiwan.
Williams van Rooij, S. (2009). Scaffolding project-based learning with the project management body of knowledge (PMBOK®). *Computers & Education, 52*(1), 210–219.
Yang, Stephen. J. H., Okamoto, T., & Tseng, S. S. (2008). A matter of context-aware ubiquitous learning. *Journal of Educational Technology & Society, 11*(2), 1–2.
Yeh, Y. F., Chen, M. C., Hung, P. H., & Hwang, G. J. (2010). Optimal self-explanation prompt design in dynamic multi-representational learning environments. *Computers & Education, 54*(4), 1089–1100.