Computers & Education 54 (2010) 289–297

Contents lists available at ScienceDirect

Computers & Education

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

A knowledge engineering approach to developing mindtools for context-aware ubiquitous learning

Hui-Chun Chu [a], Gwo-Jen Hwang [a,*], Chin-Chung Tsai [b]

[a] Department of Information and Learning Technology, National University of Tainan, 33, Sec. 2, Shulin St., Tainan city 70005, Taiwan
[b] Graduate School of Technological and Vocational Education, National Taiwan University of Science and Technology, 43, Sec. 4, Keelung Rd., Taipei 106, Taiwan

ARTICLE INFO

Article history:
Received 23 February 2009
Received in revised form 10 August 2009
Accepted 13 August 2009

Keywords:
Interactive learning environments
Mobile and ubiquitous learning
Mindtools
Knowledge engineering
Repertory grid

ABSTRACT

Recent developments in computing and mobile technologies have enabled the mobile and ubiquitous learning approach, which situates students in an environment that combines real-world and digital-world learning resources. Although such an approach seems to be innovative and interesting, several problems have been revealed when applying it to practical learning activities. One major problem is owing to the lack of proper learning strategies or tools that can guide or assist the students to learn in such a complex learning scenario. Students might feel excited or interested when using the mobile devices to learn in the real world; however, their learning achievements could be disappointing. To cope with this problem, in this study, a knowledge engineering approach is proposed to develop Mindtools for such innovative learning scenarios. Experimental results from a natural science course of an elementary school show that this innovative approach not only enhances learning motivation, but also improves the learning achievements of the students.

1. Introduction

In the past decade, researchers have developed various computer-assisted learning or web-based learning systems to provide a more adaptive learning environment with plenty of learning resources. Much attention has been focused on new learning strategies with appropriate software tools and environments (Fabos & Young, 1999), such as Computer scaffolding (Ge & Land, 2004; Williams van Rooij, 2009), the activity-theoretical approach (Liaw, Huang, & Chen, 2007), and Computer-Supported Intentional Learning Environments (CSILE database, e.g., Hakkarainen & Palonen, 2003). These learning strategies have been applied in classroom teaching with Internet access.

Although several studies have demonstrated the benefits of computer and network-based learning (e.g., Hill, 1999; Hill & Hannafin, 1997; Pena-Shaffa & Nichollsb, 2004; Tsai & Tsai, 2003; Yakimovicz & Murphy, 1995), educators have emphasized the importance and necessity of "authentic activities" in which students can work with problems from the real world (Brown, Collins, & Duguid, 1989; Minami, Morikawa, & Aoyama, 2004; Wenger, 1997). In order to situate students in authentic learning environments, it is important to place them in a series of designed lessons that combine both real and virtual learning environments (Hwang, Tsai, & Yang, 2008).

Recently, the advance of wireless communication, sensor and mobile technologies has provided unprecedented opportunities to implement new learning strategies by integrating real-world learning environments and the resources of the digital world. With the help of these new technologies, individual students are able to learn in real situations with support or instructions from the computer system by using a mobile device to access the digital content via wireless communications. Moreover, the learning system is able to detect and record the learning behaviors of the students in both the real world and the digital world with the help of the sensor technology. Such a new technology-enhanced learning model is called *context-aware ubiquitous learning* (u-learning), and it not only supports learners with an alternative way to deal with problems in the real world, but also enables the learning system to more actively interact with the learners (Hwang et al., 2008; Ogata & Yano, 2004; Yang, Okamoto, & Tseng, 2008).

Nevertheless, without proper support, the new learning scenario might become too complex for the students. 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, p1). Among the existing technologies, computers have been recognized as being a potential tool for supporting learning and instruction, such that the learners function as designers, and the computers function as Mindtools for interpreting and organizing their personal knowledge (Jonassen, 1999; Jonassen et al., 1998; Kommers, Jonassen,

* Corresponding author. Tel.: +886 915396558; fax: +886 63017001.
E-mail addresses: carolchu@mail.nutn.edu.tw (H.-C. Chu), gjhwang@mail.nutn.edu.tw (G.-J. Hwang), cctsai@mail.ntust.edu.tw (C.-C. Tsai).

0360-1315/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compedu.2009.08.023

& Mayes, 1992). Therefore, it has become an important and challenging issue to develop Mindtools to assist learners to interpret and organize their personal knowledge in a context-aware u-learning environment.

2. Relevant research

Although computer technology-enhanced learning has been widely discussed and employed in past decades, various studies have indicated the necessity and importance of ''authentic activities'' in which students can work with problems from the real world (Brown et al., 1989; Herrington & Oliver, 2000; Hwang et al., 2008; Lave, 1991). Researchers also indicated four critical tasks involved in instructional design for situated learning (Hwang et al., 2008; Young, 1993):

(1) The selection of the situation or set of situations that will afford the acquisition of knowledge that the teacher wishes each student to acquire (Chen, Kao, & Sheu, 2003; Lee, 2008; Shaw, Turvey, & Mace, 1982).
(2) The provision of the necessary ''scaffolding'' for novices to operate within the complex realistic context and still permit experts to work within the same situation (Bruner, 1986; Hwang, Yang, Tsai, & Yang, 2009; Vygotsky, 1978; Williams van Rooij, 2009).
(3) The provision of supports that enables teachers to track progress, assess information, interact knowledgeably and collaboratively with individual students or cooperating groups of students, and prepare situated learning activities to assist the students in improving their ability in utilizing skills or knowledge (Collins, 1991; de Leng, Dolmans, Jöbsis, Muijtjens, & van der Vleuten, 2009; Nussbaum et al., 2009; Ogata & Yano, 2004).
(4) The defining of the role and nature of assessment and what it means to ''assess'' situated learning (Lave & Wenger, 1991; Paige & Daley, 2009).

Mayes and de Freitas (2004) further indicated that, when designing a situated learning environment, the teacher may adopt a ''schooling'' perspective to focus on the learning objectives of a curriculum and situating specific content within a context of authentic activities.

In recent years, the efficiency and popularity of mobile and sensor technologies have attracted much attention from researchers. Several studies have been conducted to demonstrate the usage of those new technologies in supporting authentic learning. Chen et al. (2003) reported a mobile learning system for scaffolding students' learning about bird watching using handheld devices. Chen, Chang, and Wang (2008) presented a learning environment to scaffold learners with mobile devices and sensor techniques. Chu, Hwang, Huang, and Wu (2008) demonstrated a technology-enhanced authentic environment in which the learning system guided the students to learn in the real world by using sensor technology to detect the learning behaviors of individual students. It can be seen that guiding the students to learn in the real world with supports from the digital world has become an important and challenging issue.

To effectively assist the students in interpreting and organizing their personal knowledge, the provision of knowledge construction tools is needed. Mindtools have been recognized as computer-based tools and learning environments which serve as extensions of the mind. Jonassen (1999, p9) described Mindtools as ''a way of using a computer application program to engage learners in constructive, higher-order, critical thinking about the subjects they are studying''.

Educators have indicated the possibility of invoking several computer facilities as Mindtools, such as databases, spreadsheets, semantic networks (e.g., concept maps), computer conferencing, hypermedia construction, microworld environments (Dynamic Modeling Tools, e.g., active learning environments which simulate real-world phenomena), expert systems, and Information and Communication Technologies (ICT, e.g., online discussion groups and search engines) (Jonassen et al., 1998; Valcke, Rots, Verbeke, & Braak, 2007). Some of these computer facilities have been applied to practical applications and have achieved promising results. For example, Reece, Roberts, and Khoury (2003) implemented special-purpose course management systems (CMS) to serve as Mindtools. They found that CMS could not only improve communication among students and instructors, but also enhance students' current mathematical skill level and likelihood for success in a basic algebra course. In the meantime, a study concerning the use of a constructionist Mindtool approach in a course of logic, robotics, and programming for non-technical third level students was reported (Savage, Sanchez, O'Donnell, & Tangney, 2003). From the previous experiences of using Mindtools, it can be seen that integrating constructionism, Mindtools and discourse offers enormous potential to promote students' higher-order thinking skills in analysis, synthesis and evaluation. As noted by Jonassen and Carr (2000), technology can be used as a Mindtool to support the students compose deep reflective thinking that is necessary for meaningful learning.

Among those recognized Mindtools, expert systems are perhaps the most special and challenging. An expert system is an artificial intelligence program designed to simulate expert reasoning based on the knowledge elicited from domain experts. In the past decades, numerous successful cases of developing expert systems have demonstrated the benefits of applying this approach (Leitich et al., 2001; Miranda-Mena et al., 2006; Yang, Zhang, & Chen, 2008). Past experiences have also shown that the most critical task for developing an expert system is the elicitation of the knowledge or expertise from domain experts, which is known as *knowledge acquisition* (Chu & Hwang, 2008; Hwang, Chen, Hwang, & Chu, 2006; Shaw et al., 1982). Jonassen (1999) argued that the creation of the knowledge bases of expert systems is the part of the activity that engages critical thinking; that is, learners are likely to interpret and organize their personal knowledge while participating in the knowledge acquisition process. Therefore, it has become an interesting and important issue to develop Mindtools which use the knowledge acquisition approach.

In the following sections, an innovative model is proposed for developing Mindtools to support authentic learning based on an enhanced knowledge acquisition approach. Moreover, a context-aware ubiquitous learning environment has been implemented and a learning activity was conducted to demonstrate the effectiveness of this novel approach.

3. An innovative mindtool for context-aware ubiquitous learning

Jonassen (1999) indicated that the development of expert systems results in deep understanding because they provide an intellectual environment that demands the refinement of domain knowledge; moreover, the process of building expert systems (i.e., knowledge acquisition) requires learners to synthesize their knowledge by making explicit their own reasoning, and hence it improves retention, transfer, and problem-solving abilities. That is, with proper design, knowledge acquisition approaches could be innovative Mindtools for improving student learning efficacy.

Among various knowledge acquisition approaches, the repertory grid method that originates from the Personal construct theory proposed by Kelly (1955) has been recognized to be very effective. Various studies have reported the effectiveness of using the repertory grid method in assisting the domain experts to better organize their knowledge and experiences (Boose & Gaines, 1989; Chu & Hwang, 2008; Hwang et al., 2006). A single repertory grid is represented as a matrix whose columns have element labels and whose rows have construct labels. Elements could be decisions to be made, objects to be classified, or concepts to be learned. Constructs are the features for describing the similarities or differences among the elements. Each construct consists of a trait and the opposite of the trait. A 5-scale rating mechanism is usually used to represent the relationships between the elements and the constructs; i.e., each rating is an integer ranging from 1 to 5, where "1" represents that the element is very likely to have the trait; "2" represents that the element may have the trait; "3" represents "unknown" or "no relevance"; "4" represents that the element may have the opposite characteristic of the trait; and "5" represents that the element is very likely to have the opposite characteristic of the trait (Chu & Hwang, 2008).

In the following subsections, an innovative Mindtool based on an enhanced repertory grid method for conducting learning activities in authentic learning environments is presented.

3.1. Learning objectives and scenarios

In this study, the authentic learning environment is an elementary school garden consisting of 12 areas of plants as target learning objects. Each area has an instructional sign to introduce the plants in that area. The target plants are labeled with an RFID (Radio Frequency Identification) tag, and each student has a mobile device equipped with an RFID reader. In addition, wireless communication is provided, so that the mobile device can communicate with a computer server.

The students who participate in the learning activity are asked to observe and classify the target plants. While 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; therefore, the learning system is able to actively provide personalized guidance or hints to individual students by interacting with them via the mobile device.

3.2. Enhanced repertory grid model for developing mindtools

An enhanced repertory grid approach is proposed to develop Mindtools for context-aware ubiquitous learning. In the enhanced model, the rating values not only represent the tendency toward the trait or the opposite aspect of the trait, but also indicate the multi-level features of the elements. Consider the construct "Leaf-shape" that consists of the trait "Leaf-shape long and thin" and its opposite "Leaf-shape flat and round " as shown in Table 1; the rating values 1–5 not only imply the tendency toward the two poles of the construct, but also represent multi-level features of leaf shapes. For example, "Very long and thin", "Long and thin", "Other shapes", "Oblate" and "Very oblate" are the main features of the construct "Leaf-shape"; moreover, "Acicular (1.0)", "Linear (1.3)" and "Lance-shaped (1.7)" are the sub-features of the main feature "Very long and thin". The rating values are presented in the "$X \cdot Y$" form to represent the tendency of sub-feature "Y" to main feature "X", such that more precise descriptions can be used to represent the relationships between the elements and the constructs. In this enhanced model, X is the main tendency degree of the features; $Y = X + \frac{i-1}{r}$ represents the tendency degree of the ith sub-feature, where r is the number of sub-features in that main tendency degree. For example, in the first row of Table 1, the main tendency degree of "Very long and thin" is 1, and the tendency degrees of the sub-features "Acicular", "Linear", and "Lance-shaped" are 1+(1–1)/3 = 1.0, 1+(2–1)/3 = 1.3 and 1+(3–1)/3 = 1.7, respectively.

The innovative approach consists of two stages; that is, the objective knowledge construction stage and the student knowledge construction stage.

In the first stage, the domain experts (teachers) are asked to determine the target learning objects and construct the objective repertory grid by following the standard repertory grid method:

Step 1: Elicit all of the elements (target learning objects) from the expert. The elements (e.g., "Golden Chinese banyan", "Arigated-leaf croton", "Cuphea", "Indian almond", "Money Tree" and "Pink ixora") provided by the expert are placed across the top of a grid.

Step 2: Rate all of the [element, construct] entries of the grid with the enhanced rating scheme. An illustrative example is given in Table 2.

Table 1
Illustrative example of an enhanced repertory model.

Trait	Main tendency degrees					Opposite
	1	2	3	4	5	
Leaf-shape long and thin	Very long and thin: Acicular (1.0)	Long and thin: Oblanceolate (2.0)	Other shapes: Spatulate (3.0)	Oblate: Obovate (4.0)	Very oblate: Round (5.0)	Leaf-shape flat and round
	Linear (1.3) Lance-shaped (1.7)	Long Elliptic (2.3) Ovate (2.7)	Cuneate (3.3) Cordate (3.7)	Reniform (4.3) Obcordate (4.7)		
The leaf has a tapering point	Tapering to a long point: Acute (1.0)	Arrowhead-shaped point: Acuminate (2.0)	Stem attaches to tapering point: Mucronulate (3.0)	Round with a blunt tip: Obovate (4.0)	Leaf with a hollow point: Obcordate (5.0)	The leaf has a hollow point
	Falcate (1.5)			Truncate (4.5)		
Perfectly smooth leaf edge	Smooth, no bumps: Entire (1.0)	Shallow bumps: Ciliate (2.0)	Indented edges: Dentate (3.0)	Deeply cut with sharp, irregular teeth: Incised (4.0)	Deep indents or sinuses: Lobed (5.0)	The leaf edge has deep indents
		Serrulate (2.5)	Serrate (3.5)		Pinnatifed (5.5)	

Table 2
Illustrative example of an enhanced repertory grid completed by the teacher.

Trait construct	Golden Chinese banyan	Arigated-leaf croton	Cuphea	Indian almond	Money Tree	Crown of thorns	Pink ixora	Opposite construct
Leaf-shape long and thin	2.3, 2.7	2.0	2.0	4.0	2.3	2.0, 2.3	2.3	Leaf-shape flat and round
The leaf has a tapering point	3.0	1.0	1.0	4.0	2.0	1.0	3.0	The leaf has a hollow point
Perfectly smooth leaf edge	1.0	1.0	4.0	1.0	1.0	5.0	1.0	The leaf edge has deep indents
The leaf vein has few branches	2.3	3.0	2.3	2.0	3.0	3.3	3.0	The leaf vein has many branches

In the second stage, an interactive learning procedure (as shown in Fig. 1) is used to guide the students to observe and compare the features of the target objects in the authentic learning environment based on the enhanced repertory grid given by the teacher (which is referred to as the *objective repertory grid* in the following).

Step 1: Display the structure of the objective repertory grid to individual students.
Step 2: Guide the students to observe and describe the main features of each learning object based on the objective repertory grid structure.
For each construct (trait/opposite pair), guide the students to observe the target learning objects, and fill in the <construct, element > value for the elements in each row of the grid. In addition to guiding individual students to the location of each target object, a question-based model is used to guide individual students to observe and compare the features of the target objects. That is, each step of the guidance is presented as a multiple-choice question, in which the candidate answers are the main features of the construct to be observed. For example, the candidate answers concerning the observation of "leaf-point" are the features of the construct "leaf-point" that consists of the trait "The leaf has a tapering point" and the opposite "The leaf has a hollow point"; that is, 1 means "Tapering to a long point", 2 means "Arrowhead-shaped point", 3 means "Stem attaches to a tapering point", 4 means "Round with a blunt tip", and 5 means "Leaf with a hollow point", as shown in the second row of Table 1.
Step 3: For a construct, compare the main-feature description (rating value) for each learning object (element) given by the student with the corresponding rating given by the expert.
Step 3.1: If the main-feature description is incorrect, guide the student to observe another learning object with the "incorrect main-feature" and compare it with the target object. This step aims to assist the students to reflect on their previous decisions by comparing the features of the learning objects in the real world such that their knowledge and critical thinking ability can be improved.
For example, the student observes the plant (target object) "Arigated-leaf croton" and describes its "Leaf-shape" as "obovate" (rating value = 4.0). By comparing the student's answer with the rating given by the teacher (i.e., "oblanceolate", rating value = 2.0) in Table 2, it is found that the student's answer is incorrect. From the objective repertory grid, it can be seen that the "Leaf-shape" of another learning object "Indian almond" is "obovate", which matches the incorrect answer given by the student. Therefore, the student is guided to observe the "Indian almond", and compare its "Leaf-shape" with that of the "Arigated-leaf croton". After making the comparison, the student will be asked to answer the question again. This step will be repeated until the student correctly identifies the feature of the target object.

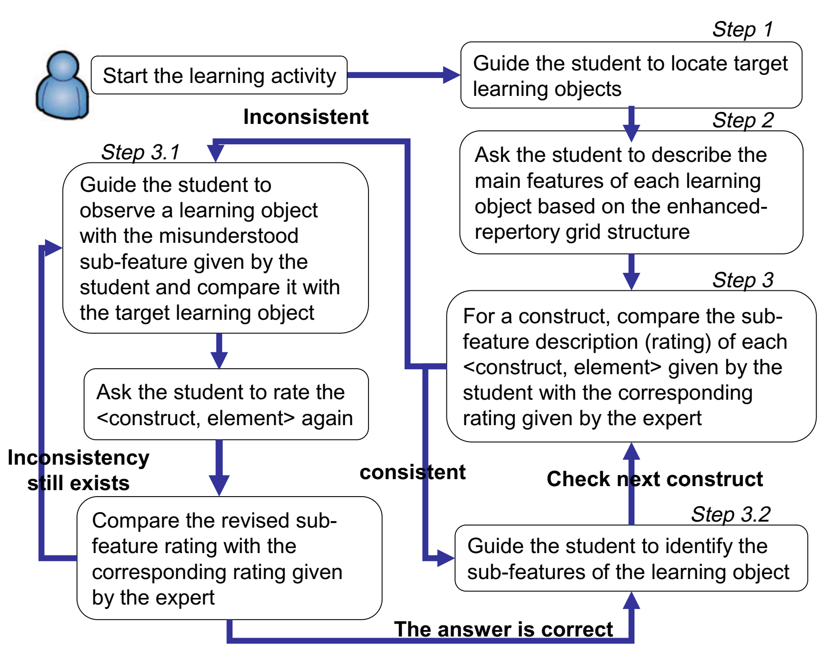

Fig. 1. Learning procedure based on the enhanced repertory grid model.

Step 3.2: If the main-feature description is correct, guide the student to describe the learning object with one of the candidate sub-features. Supplemental materials will be given if the student fails to correctly identify the sub-features of the learning object.
Step 4: Repeat Step 3 until all of the main features and their sub-features are correctly identified by the student.

Note that some features of the learning objects need to be ‘‘felt” rather than ‘‘observed”. For example, to identify whether the leaf surface of a plant is ‘‘smooth” or ‘‘coarse”, the students need to feel the leaf. For such features, it might be difficult for the students to have exactly the same ‘‘feeling” as the teacher does; therefore, some supplemental materials that show the detailed information of the features. For example, while guiding the students to ‘‘feel” different coarse levels of the leaf surface, relevant micrographs will be given. With the help of those micrographs, the students will be able to better recognize the actual features of leaf surface while touching and feeling the leaves.

3.3. Development of a mindtool for context-aware ubiquitous learning

Based on this innovative approach, Mobile Knowledge Constructor (MKC), a Mindtool for context-aware ubiquitous learning, has been developed to assist the students in observing and classifying learning objects in the real world. MKC 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.

For example, after guiding the student to find the target object ‘‘Lalang Grass” on the campus, MKC asks the student to observe the ‘‘leaf-point” of ‘‘Lalang Grass” and answer the question generated from the enhanced repertory grid model.

If the student failed to correctly identify the plant feature, the MKC system will try to guide him/her to observe another target object which exhibits the incorrect answer, and compare the difference between the features of the two target objects. For example, if an incorrect answer ‘‘Round with a blunt tip” is given by the student for the ‘‘leaf shape” of ‘‘Lalang Grass”, the learning system will guide the student to find the plant ‘‘Indian almond” that really has a leaf point that is ‘‘Round with a blunt tip” and compare it with the leaf point of the original target ‘‘Lalang Grass”. To assist the student in easily finding the plant ‘‘Indian almond”, the MKC system shows a campus map which marks the plant ‘‘Indian almond” and the student’s location.

When the student is close to the plant ‘‘Indian almond”, the MKC system will guide him/her to observe and compare the leaf shapes of ‘‘Indian almond” and ‘‘Lalang Grass”. The student is then asked to walk back to the target plant ‘‘Lalang Grass”, and answer the question concerning ‘‘the leaf shape of Lalang Grass” again.

4. Experiment and analysis

To evaluate the effectiveness of the innovative approach, an experiment was conducted on a natural science course of an elementary school which is located in a small town in southern Taiwan. In the following subsections, the design and analysis of the results of the experiment are given in detail.

4.1. Participants

Like most country schools in Taiwan, the scale of the elementary school is small. Its total student population is 88. The participants of this study are 13 fifth-grade students taught by the same teacher. The ages of the participants range from 10 to 11 and their average age is 10.76. After receiving the fundamental plant knowledge in their natural science course, the participants were randomly divided into a control group ($n = 6$) and an experimental group ($n = 7$).

4.2. Procedure

Fig. 2 shows the procedure of the experiment. In the first stage (5 weeks), the teacher was guided to represent the classification knowledge of the target plants based on the enhanced repertory grid model.

In the second stage, after receiving fundamental knowledge of plants in the natural science course, the 13 students were randomly divided into a control group and an experimental group, and were asked to answer a pre-questionnaire and take a pre-test. The question items in the pre-questionnaire were concerned with the students’ attitudes to the plants and the natural science course. The pre-test aimed to evaluate the students’ basic knowledge about the plants on their campus.

The students in the experimental group were then arranged to observe and compare the features of 12 plants on the campus using MKC, while those in the control group were guided by the teacher and were asked to record their observations on a learning sheet. After conducting the learning activity, the students were asked to take a post-test and answer a post-questionnaire.

After completing the post-test and the post-questionnaire, the students in the control group were also arranged to experience learning with MKC; furthermore, all of the students in both the experimental and the control group were interviewed to elicit their opinions about the innovative approach.

4.3. Pre- and post-test results

The pre-test aimed to ensure that both groups of students had the equivalent basic knowledge required for learning the subject unit. The mean and standard deviation of the pre-test were 55.86 and 15.07 for control group, and 57.67 and 13.98 for experimental Group. According to the t-test result ($t = -0.223$), it is evident that the two groups of students had equivalent abilities prior to taking this unit.

The post-test consisted of two types of test items: Type I focused on evaluating the students’ basic knowledge about plants; Type II aimed at evaluating their ability in classifying and comparing plants based on their features, which is the objective of the subject unit. That is, for each student, the post-test score was equal to the sum of the Type I and the Type II scores.

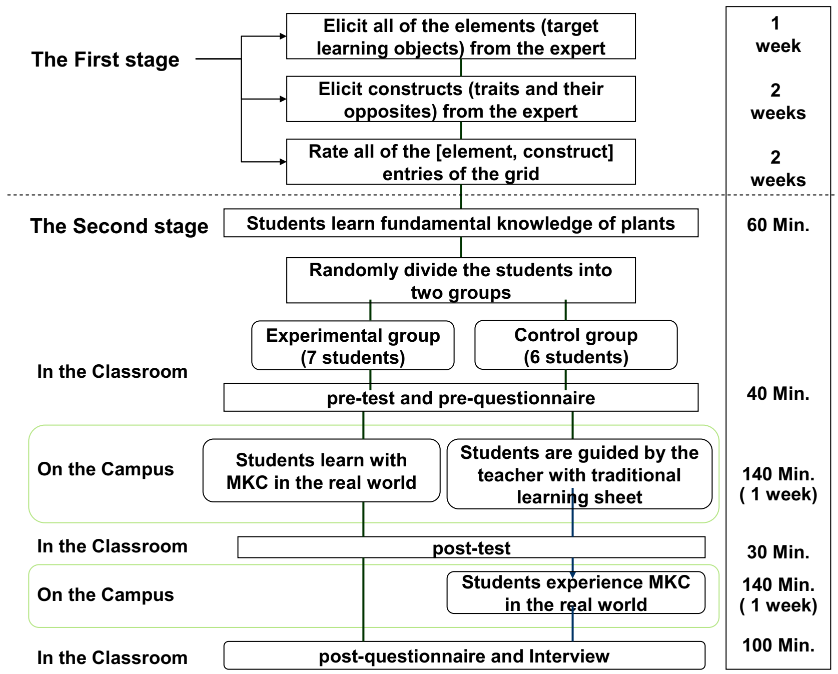

Fig. 2. Procedure of the context-aware u-learning activity.

Before analyzing the experimental results, it is important to consider whether the data with such small sample size can be examined by applying ANCOVA (Hogg & Tanis, 2006). When the sample size of a study is small, it is necessary to validate the application of parametric tests by investigating the homogeneity of variance and the normality of the sample distribution (Ge & Land, 2003; Nam & Smith-Jackson, 2007). Therefore, in this study, the Levene's test was applied to test the homogeneity of variance and the Shapiro–Wilk test was used to investigate whether the distribution satisfied the normality criterion (Conover, 1998; Shapiro & Wilk, 1965).

Both the results on the data of this study revealed that all pair-wise tests had non-significant outcome ($p > 0.05$), suggesting that the samples had homogenous variances and normal distribution of data. This supports the usage of ANCOVA tests. Furthermore, researchers also suggested reporting the effect size when the sample is small (Ge, Chen, & Davis, 2005; Ge & Land, 2003). Therefore, in the followings, we will apply ANCOVA tests to the analyses of the experimental results and report the effect size."

To explore how the two groups were affected by the treatments in terms of student' abilities of basic plant knowledge and the classification knowledge of plants, an analysis of covariance (ANCOVA) on post-test scores, with the pre-test as the covariate, was conducted on the Type I test items (basic knowledge of the 12 target plants) and Type II test items (ability of classifying and comparing target plants based on their features) to determine any significance between these two groups. Therefore, three ANCOVA tests were performed on the post-test scores, the Type I scores and the Type II scores, respectively.

Table 3 shows the ANCOVA results of the post-test, Type I and Type II scores; in addition, the original means and standard deviations are also presented. The mean and standard deviation of the post-test were 40.33 and 6.28 for the control group, and 55.29 and 13.87 for the experimental group. For the Type I test items, the mean and standard deviation were 31.67 and 8.76 for the control group, and 35.71 and 7.87 for the experimental group; for the Type II test items, the mean and standard deviation were 8.67 and 5.05 for the control group, and 19.57 and 7.89 for the experimental group.

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 ($F = 9.573$, $p < .05$). Furthermore, for the scores of the Type II test items, which focus on the ability of observing and comparing the differences between the 12 target plants, the students in the experimental group had significantly better achievements than

Table 3
Descriptive data, ANCOVA, and effect sizes of the post-test results.

Variable		*N*	Mean	SD	Adjusted mean	Std. error	*F value*	*p*	*d*
Post-test	Experimental group	7	55.29	13.781	55.671	3.462	9.573*	0.011	1.39
	Control group	6	40.33	6.282	39.883	3.741			
Type I: the fundamental knowledge of the plants	Experimental group	7	35.71	7.868	36.085	2.050	2.579	0.139	.49
	Control group	6	31.67	8.756	31.234	2.214			
Type II: the classification and observation knowledge of the plants	Experimental group	7	19.57	7.892	19.586	2.676	7.690*	0.020	1.65
	Control group	6	8.67	5.046	8.649	2.891			

* $p < .05$.

those in the control group ($F = 7.690$, $p < .05$). This result implies that the innovative approach is helpful to students in improving their classification and comparison ability.

In addition, it was found that the Type I scores of students in the experimental group did not have significant different in comparison with those of the students in the control group, implying that the innovative approach was more effective in improving the students' classification knowledge (Type II) than improving their basic knowledge (Type I) of plants. This finding was expectable since Type II test was more relevant to the functionality of the MKC, which guided the students to observe and classify plants in the school campus.

Furthermore, from the descriptive statistics of the Type I scores, it was found that the students in the experimental group had better achievements than those in the control group (i.e., the original means were 35.71 versus 31.67), although the difference was not significant. This implies that MKC could also be helpful to the students in improving their basic knowledge of plants, although the effect was not so apparent. The reason for the non-significant difference could be due to the small sample size; therefore, it is reasonable to expect that significant difference might be derived if the sample size is large enough.

As the number of students who participated in the experiment is small, we further computed the effect size of the test results based on the Cohen's d value (Cohen, 1988); Cohen hesitantly defined effect sizes as "small, $d = .2$,", "medium, $d = .5$," and "large, $d = .8$"; usually a test result is said to have a large effect size if its Cohen's d value is greater than .80. As shown in Table 3, for the post-test and Type II test items, the Cohen's d of the post-test are 1.39 and 1.65, respectively, which is much greater than 0.8. The effect size of 1.39 and 1.65 indicate that the mean of post-test and Type II test items of experimental group are at the 91.7 and 95 percentile of the control group. This result further reveals that the finding (i.e., the innovative approach is helpful to students in improving their classification and comparison ability) has a very large effect size.

4.4. Results of questionnaire and interview responses

After conducting the experiment, the students in the control group were arranged to experience the learning with MKC. The survey was preformed by asking the students to answer a questionnaire with a six-point Likert-scale, where 1 represents "strongly disagree" and 6 represents "strongly agree". It was found that most of the students showed highly interested in learning with MKC in the real-world learning environment. For example, 100% of the students would like to use this learning system in the future, and 92% of them would recommend this system to others. Moreover, all of the students would like to know if this PDA-based Mindtool can be applied to other courses to improve their learning performance.

From the "interest" viewpoint, the average rating for being interested in taking the natural science course changed from 4.85 to 5.31, which implies that the use of the PDA-based Mindtool is helpful in promoting learning interests in natural science courses. Relevant feedback can also be found in other questionnaire items, such as "Since participating in the learning activity, I am more interested in observing and exploring the features of plants than before" (5.00), "I am more interested in taking the natural science course since participating in the learning activity" (5.31), "The use of PDAs will make the learning process more interesting" (5.46), "This innovative way of learning makes me want to know more about plants" (5.38), and "Using a PDA to learn stimulates my learning motivation" (5.54).

From the "helpfulness" viewpoint, most of the students felt that the PDA-based Mindtool was helpful to them, and they tried hard to follow the guidance of the learning system (5.0); in addition, the average rating concerning the students' confidence in recognizing the campus plants changed from 4.46 to 5.3, which implies that the students felt the "helpfulness" of the innovative approach in their natural science course. Relevant feedback can be found in other questionnaire items, such as "I know more about the features of the campus plants since participating in this learning activity" (5.54) and "Using a PDA as a learning device provides better assistance than the traditional way of tutoring" (5.46).

Furthermore, we interviewed all of the students and the teacher to acquire more detailed feedback. The feedback from all of the five high achievement students showed their interests toward the innovative approach. For example, one of the students stated that, "I feel tired today since I need to run around from the plants to plants for comparing their features. But I am very happy to have this opportunity to experience the use the PDA. This is a very innovative way to learn. I learn much about the differences between those plants via following the learning guidance of the PDA to compare their features. Moreover, I was able to control my own learning progress during this activity. When completing the observation of a plant, I felt very happy and proud. I used to ignore the plants on the campus, but now I notice them all the time. They look lovely to me now. I really prefer to use this innovative way to learn in the future."

More importantly, some encouraging findings were derived from four low achievement students. Those students expressed a strong willingness to have more chances to learn with the PDA-based Mindtool; they also expressed their willingness to use the PDA-based Mindtool in other courses, just as the high achievement students did. One of the low achievement students stated that, "This learning activity is very interesting. It makes me understand the campus plants better. I did not pay attention to the campus plants before, but now I feel it is very interesting to compare the differences between the plants. I would like to use the PDA and the learning system to learn other courses." Another student stated that, "I needed to run from one plant to another during the learning process, which used to make me feel tired and bored; however, now I feel it is very exciting and worthwhile to complete the observations of each plant."

The teacher also showed positive feedback to the innovative approach. He stated that, "In the beginning, the use of PDA was only an interesting trial to me. However, when I was guided to provide the target repertory grid, the entire scaffolding strategy became clear and meaningful." After knowing the post-test results of the experimental group and the control group, the teacher further addressed that, "It is surprising that the effect of the repertory grid-oriented u-learning approach is so good. This approach is promising and should be applied to more courses to benefit more students."

In addition, the teacher also gave some suggestions for our future work; he indicated that, "It seems that the learning activity is too difficult to some students owing to the large number of learning objects taken into account in the same time. It would be better to decrease the number of learning objects and extend the learning time." He also suggested that, "It is time-consuming for teachers to provide the target repertory grids. It would be better to have a tool to systematically assist teachers in defining the content of the repertory grids."

5. Conclusions

The popularity of mobile and wireless communication technologies has attracted much attention from researchers in recent years. Several studies have been conducted to investigate the effectiveness of mobile and ubiquitous learning which can provide an opportunity for students to keep accessing digital resources while learning in real-world scenarios. For example, Chen et al. (2003) reported a mobile learning system for scaffolding students in a bird-watching learning activity. Such learning activities usually receive promising feedback from the students owing to the novelty and pleasure of using mobile devices outside the classroom. Therefore, most researchers and school teachers have treated the mobile devices and wireless communication equipment as a convenient channel for students to access digital resources from the Internet. Nevertheless, the issue of developing new strategies or tools to improve the learning efficacy of students in mobile and ubiquitous learning environments is seldom discussed.

In this paper, a knowledge engineering approach is proposed to develop Mindtools for context-aware u-learning. The developed Mindtool has been applied to a learning activity of a natural science course in an elementary school. The experimental results show that the innovative approach not only promotes learning motivation, but also improves the learning achievements of individual students. This finding is quite different from those reported by previous studies (Chu et al., 2008; El-Bishouty, Ogata, & Yano, 2007; Peng, Chou, & Chang, 2008; Rau, Gao, & Wu, 2008), which mainly focused on the learning motivation, the learning behaviors and the technology acceptance issues for mobile and ubiquitous learning. It also encourages researchers to pay more attention to the development of mobile and ubiquitous learning strategies and tools to benefit students in improving their learning efficacy.

In addition to the benefits of improving learning efficacy for individual students, mobile devices and wireless communications provide a good way to conduct cooperative learning activities. Therefore, one of our future projects is to extend MKC to a cooperative learning version; that is, a Mindtool that allows students to share and exchange ideas and experiences while observing learning objects in the real world. Moreover, to introduce this innovative approach into the classroom, it is important to ease the burden of teachers in providing the target repertory grids. Relevant studies concerning this issue have been reported by several researchers who emphasized the importance and necessity of developing knowledge acquisition systems to obtain quality knowledge from domain experts (Boose & Gaines, 1989; Chu & Hwang, 2008; Hwang et al., 2006). Therefore, we are planning to develop a knowledge acquisition tool, which can systematically guide the teachers to determine the structure and the content of the repertory grids.

Acknowledgements

This study is supported in part by the National Science Council of the Republic of China under Contract No. NSC 96-2520-S-024-004-MY3 and NSC 98-2631-S-024-001.

References

Boose, J. H., & Gaines, B. R. (1989). Knowledge acquisition for knowledge-based systems: Notes on the state-of-the-art. *Machine Learning, 4*(4), 377–394.
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 and Education, 50*(1), 77–90.
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.
Chu, C. H., & Hwang, G. J. (2008). A Delphi-based approach to developing expert systems with the cooperation of multiple experts. *Expert Systems with Applications, 34*(4), 2826–2840.
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.
Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.
Collins, A. (1991). The role of computer technology in restructuring schools. *Phi Delta Kappan, 73*(1), 28–36.
Conover, W. J. (1998). *Practical nonparametric statistics* (3rd ed.). New Jersey: Wiley.
de Leng, B. A., Dolmans, D. H. J. M., Jöbsis, R., Muijtjens, A. M. M., & van der Vleuten, C. P. M. (2009). Exploration of an e-learning model to foster critical thinking on basic science concepts during work placements. *Computers and Education, 53*(1), 1–13.
El-Bishouty, M. M., Ogata, H., & Yano, Y. (2007). PERKAM: Personalized knowledge awareness map for computer supported ubiquitous learning. *Journal of Educational Technology and Society, 10*(3), 122–134.
Fabos, B., & Young, M. D. (1999). Telecommunication in the classroom: Rhetoric versus reality. *Review of Educational Research, 69*(3), 217–259.
Ge, X., Chen, C.-H., & Davis, K. A. (2005). Scaffolding novice instructional designers' problem-solving processes using question-prompts in a web-based learning environment. *Journal of Educational Computing Research, 33*(2), 219–248.
Ge, X., & Land, S. M. (2003). Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development, 51*(1), 21–38.
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 and Development, 52*(2), 5–22.
Hakkarainen, K., & Palonen, T. (2003). Patterns of female and male students' participation in peer interaction in computer-supported learning. *Computers and Education, 40*(4), 327–342.
Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research and Development, 48*(3), 23–48.
Hill, B. (1999). A conceptual framework for understanding information seeking in open-ended information system. *Educational Technology Research and Development, 47*(1), 5–27.
Hill, J. R., & Hannafin, M. J. (1997). Cognitive strategies and learning from the World Wide Web. *Educational Technology Research and Development, 45*(4), 37–64.
Hogg, R. V., & Tanis, E. A. (2006). *Probability and statistical inference* (7th ed.). New Jersey: Prentice Hall.
Hwang, G. H., Chen, J. M., Hwang, G. J., & Chu, H. C. (2006). A time scale-oriented approach for building medical expert systems. *Expert Systems with Applications, 31*(2), 299–308.
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 and Society, 11*(2), 81–91.
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 and Education, 53*(2), 402–413.
Jonassen, D. H., Carr, C., & Yueh, H. P. (1998). Computers as Mindtools for engaging learners in critical thinking. *TechTrends, 43*(2), 24–32.
Jonassen, D. H. (1999). *Computers as Mindtools for schools, engaging critical thinking*. Englewood Cliffs, NJ: Prentice-Hall.
Jonassen, D. H., & Carr, C. S. (2000). Mindtools: Affording multiple knowledge representations for learning. In S. P. Lajoie (Ed.). *Computers as cognitive tools. No more walls* (Vol. 2, pp. 165–196). Hillsdale, NJ: Lawlence Erlbaum Associates, Inc.
Kelly, G. A. (1955). *The psychology of personal constructs* (Vol. 1). New York: W.W Norton.
Kommers, P., Jonassen, D. H., & Mayes, T. (Eds.). (1992). *Cognitive tools for learning*. Heidelberg, FRG: Springer.
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.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.
Lee, L. D. (2008). *Toward an understanding of the use of film dubbing activities in the EFL classroom through situated learning perspectives*. Unpublished doctoral dissertation, National Chengchi University, Taipei, Taiwan.

Leitich, H., Kiener, H. P., Kolarz, G., Schuh, C., Graninger, W., & Adlassnig, K. P. (2001). A prospective evaluation of the medical consultation system CADIAG-II/RHEUMA in a rheumatological outpatient clinic. *Methods of information in medicine, 40*(3), 213–220.

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.

Mayes, T., & de Freitas, S. (2004). Review of e-learning theories, frameworks and models. JISC E-learning models study report, London. The joint information systems committee. <http://www.jisc.ac.uk/elp_outcomes.html>.

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

Miranda-Mena, T. G., Benítez, U. S. L., Ochoa, J. L., Martínez-Béjar, R., Fernández-Breis, J. T., & Salinas, J. (2006). A knowledge-based approach to assign breast cancer treatments in oncology units. *Expert Systems with Applications, 31*(3), 451–457.

Nam, C. S., & Smith-Jackson, T. L. (2007). Web-based learning environment: A theory-based design process for development and evaluation. *Journal of Information Technology Education, 6*, 23–43.

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

Ogata, H., & Yano, Y. (2004). *Context-aware support for computer-supported ubiquitous learning.* Paper presented at the 2nd IEEE international workshop on wireless and mobile technologies in education, March, 2004. JhongLi, Taiwan.

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.

Pena-Shaffa, J. B., & Nichollsb, C. (2004). Analyzing student interactions and meaning construction in computer bulletin board discussions. *Computers and 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 and Society, 11*(2), 54–66.

Rau, P. L. P., Gao, Q., & Wu, L. M. (2008). Using mobile communication technology in high school education: Motivation, pressure, and learning performance. *Computers and Education, 50*(1), 1–22.

Reece, G. A., Roberts, C. H., & Khoury, H. Q. (2003). CMS as Mindtools for enhancing student engagement in advising and assessment: Lessons learned from design of math advisor. In *Proceedings of the 2003 IEEE international professional communication conference (IPCC 2003)* (pp. 314–321). Washington, DC: IEEE Computer Society Press.

Savage, T., Sanchez, I. A., O'Donnell, F., & Tangney, B. (2003). Using robotic technology as a constructionist Mindtool in knowledge construction. In *Proceedings of the third IEEE international conference on advanced learning technologies (ICALT'03)* (pp. 324–325). Washington, DC: IEEE Computer Society Press.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality. *Biometrika, 52*(3), 591–611.

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.

Tsai, M. J., & Tsai, C. C. (2003). Information searching strategies in web-based science learning: The role of Internet self-efficacy. *Innovations in Education and Teaching International, 40*(1), 43–50.

Valcke, M., Rots, I., Verbeke, M., & Braak, J. V. (2007). ICT teacher training: Evaluation of the curriculum and training approach in Flanders. *Teaching and Teacher Education, 23*(6), 795–808.

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

Wenger, E. (1997). *Communities of practice: Learning, meaning, and identity*. Cambridge, UK: Cambridge University Press.

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

Yakimovicz, A. D., & Murphy, K. L. (1995). Constructivism and collaboration on the Internet case study of a graduate class experience. *Computers and Education, 24*(3), 203–209.

Yang, Stephen J. H., Okamoto, T., & Tseng, S. S. (2008). A matter of context-aware ubiquitous learning. *Journal of Educational Technology and Society, 11*(2), 1–2.

Yang, Stephen J. H., Zhang, J., & Chen, I. Y. L. (2008). A JESS-enabled context elicitation system for providing context-aware Web services. *Expert Systems with Applications, 34*(4), 2254–2266.

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