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An Expert System-based Context-Aware Ubiquitous Learning Approach for Conducting Science Learning Activities

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ABSTRACT

Context-aware ubiquitous learning has been recognized as being a promising approach that enables students to interact with real-world learning targets with supports from the digital world. Several researchers have indicated the importance of providing learning guidance or hints to individual students during the context-aware ubiquitous learning process. In this study, an expert system-based guidance approach is proposed for conducting effective context-aware ubiquitous learning activities based on the domain knowledge provided by experienced teachers. To evaluate the effectiveness of the proposed approach, an experiment on a learning activity in a senior high school Geosciences course has been conducted. The experimental results show that, with this new approach, the students' learning achievements have been significantly improved in terms of several cognitive processes in Bloom's taxonomy of educational objectives, such as "analyzing" and "evaluating." Consequently, it is concluded that the context-aware ubiquitous learning system with the interactive guiding approach has benefited the students in enhancing their higher order thinking competences.

Keywords

Ubiquitous learning, Expert systems, Mobile technology, Science courses, RFID

Background and objectives

Educators have indicated the importance of learning from observing or interacting with real-world learning targets (Arnseth, 2008; Rogers et al., 2005). In the traditional approach, a teacher usually needs to guide dozens of students to learn in the field or in science laboratories to interact with those learning targets (Hwang & Chang, 2011; Lin, Hsieh, & Chuang, 2009; Wu, Hwang, Su, & Huang, 2012). Researchers have indicated that such a learning approach has several problems. One is the lack of personalized learning guidance and feedback, since a teacher usually needs to face dozens of students; therefore, some students might fail to keep up with the teaching progress (Shih, Chuang, & Hwang, 2010). Another problem is the lack of an effective tool to help the students organize their findings during the observing and detecting process; consequently, the students might memorize some features of individual learning targets, but without being able to compare and differentiate them (Hwang, Chu, Lin, & Tsai, 2011).

The advancements of mobile and wireless communication technologies seem to provide an opportunity to cope with these problems (Looi et al., 2009; Peng et al., 2009). More and more studies that use mobile and wireless communication technologies to conduct real-world learning activities have been reported in recent years. For example, Wong, Chin, Tan and Liu (2010) developed a mobile learning environment to conduct Chinese idiom learning activities; Hwang and Chang (2011) emplyed mobile and wireless communication technologies to support in-field learning activities of a social science course. Some researchers have further employed sensing technologies, such as RFID (Radio Frequency Identification) and QR (Quick Response) codes, to detect the location of students during the learning process (Chen, Chang, & Wang, 2008; Hwang, Kuo, Yin, & Chuang, 2010; Ogata & Yano, 2004). With the help of sensing technologies, students can easily access supplementary materials on the server without inputting web addresses or requests; instead, they only need to read the tags on the learning targets with the sensing devices (Chen et al., 2009; Hwang, Wu, & Ke, 2011; Hwang, Wu, Zhuang, & Huang, 2013; Lin, 2007). Hwang, Tsai and Yang (2008) have named such a learning approach that employs mobile, wireless communication and sensing technologies to provide learning supports in real-world environments *context-aware ubiquitous learning*, which is called *u-learning* in the following discussions for short.

In the meantime, researchers have pointed out the necessity of providing effective learning strategies or tools to assist students in interpreting and organizing what they have learned from such authentic learning environments with complex and rich resources (Chu, Hwang, & Tsai, 2010; Hwang, Shi, & Chu, 2011; Chiou, Tseng, Hwang, & Heller, 2010; Hwang, Wu, & Kuo, 2013). Jonassen, Carr, and Yueh (1998, p. 1) have formally defined such tools as "Mindtools," which they describe as "Computer applications that, when used by learners to represent what they know, necessarily engage them in critical thinking about the content they are studying."

Among the existing approaches to developing Mindtools, expert systems have been recognized as being an effective tool for providing personalized guidance or suggestions based on domain knowledge elicited from experts or experienced teachers (Cragun & Steudel, 1987; Edwards, McDonald, & Young, 2009; Jankowicz, 2004). Researchers have indicated that, with the help of expert systems, students are able to reorganize their knowledge for identifying the similarities and differences between learning targets (Ford, Petry, Adams-Webber, & Chang, 1991; Hwang, Chu, Lin, & Tsai, 2011; Jonassen, Carr, & Yueh, 1998). Among various objectives of science education, fostering identification and differentiating competences of students has been recognized as being an important and challenging aim (National Research Council, 2000). Such a "differentiating" ability has been categorized by Anderson, Krathwohl, Airasian, Cruickshank, Mayer, Pintrich et al. (2001) as being an "analyze" competence, which includes the cognitive processes of "focusing," "selecting," "discriminating" and "distinguishing."

Therefore, in this study, an expert system is developed for supporting context-aware ubiquitous learning activities based on a grid-based knowledge acquisition approach. Moreover, an experiment is conducted on a Geosciences learning activity to evaluate the performance of the proposed approach. The objective of this study is to investigate whether the expert system is helpful to the students in improving their u-learning performance and enhancing their higher order thinking competences via providing learning guidance and hints in the fields.

Development of an expert system for context-aware ubiquitous learning

An expert system is a computer program developed to simulate the reasoning and decision-making process of domain experts based on the knowledge elicited from the experts (Chu, Hwang, & Tsai, 2010). Various successful applications of expert systems have shown the effectiveness of this approach, such as medical diagnosis, web service, and education (Chu & Hwang, 2008; Leitich et al., 2001; Liebowitz, 1997; Yang, Zhang, & Chen, 2008).

The aim of this study is to develop an expert system to support context-aware ubiquitous learning activities that engage students in developing and organizing knowledge for differentiating a set of learning targets in the real world, which has been recognized as being a higher order thinking ability by researchers (Anderson et al., 2001; Cartwright, 2002). During the learning process, the students are guided by the expert system, which employs guiding strategies and domain knowledge provided by experienced teachers in providing learning suggestions, to observe the learning targets and to collect data for identifying and differentiating the targets.

Figure 1 shows the structure of the expert system, which consists of an inference engine, a knowledge base and a web-based interface. The inference engine and web interface were implemented using Microsoft Visual Studio 2008 and Windows Mobile 6 Professional SDK. The knowledge base was developed with Microsoft SQL Server 2005. Moreover, a C# program was developed to access the RFID tag information from the reader on the Personal Digital Assistant (PDA) that served as the mobile learning device in this study.

The knowledge base of the expert system is represented by a tabular "repertory grid," which is a matrix with columns representing elements and rows representing constructs (Kelly, 1955). An element can be a decision to be made, an object to be classified or a concept to be learned. A construct is a characteristic or a feature for describing or classifying the elements. It consists of a trait (e.g. hard), and the opposite of that trait (e.g., soft) for identifying the elements (e.g., a set of target rocks). Moreover, the value ranging from 1 to k, where k is an odd integer, assigned to an element-construct pair, represents the relationship between the element and the construct. For most applications of the repertory grid, a rating mechanism with $k = 5$ is usually used to represent the relationships (Chu & Hwang, 2008; Chu, Hwang, & Tseng, 2010). In such a 5-scale rating mechanism, "1'' represents "highly inclined to the trait," ''2'' represents "more or less inclined to the trait," ''3'' represents ''no inclination'' or ''no relevance,'' ''4'' represents "more or less inclined to the opposite" and ''5'' represents "highly inclined to the opposite" (Chu & Hwang, 2008).

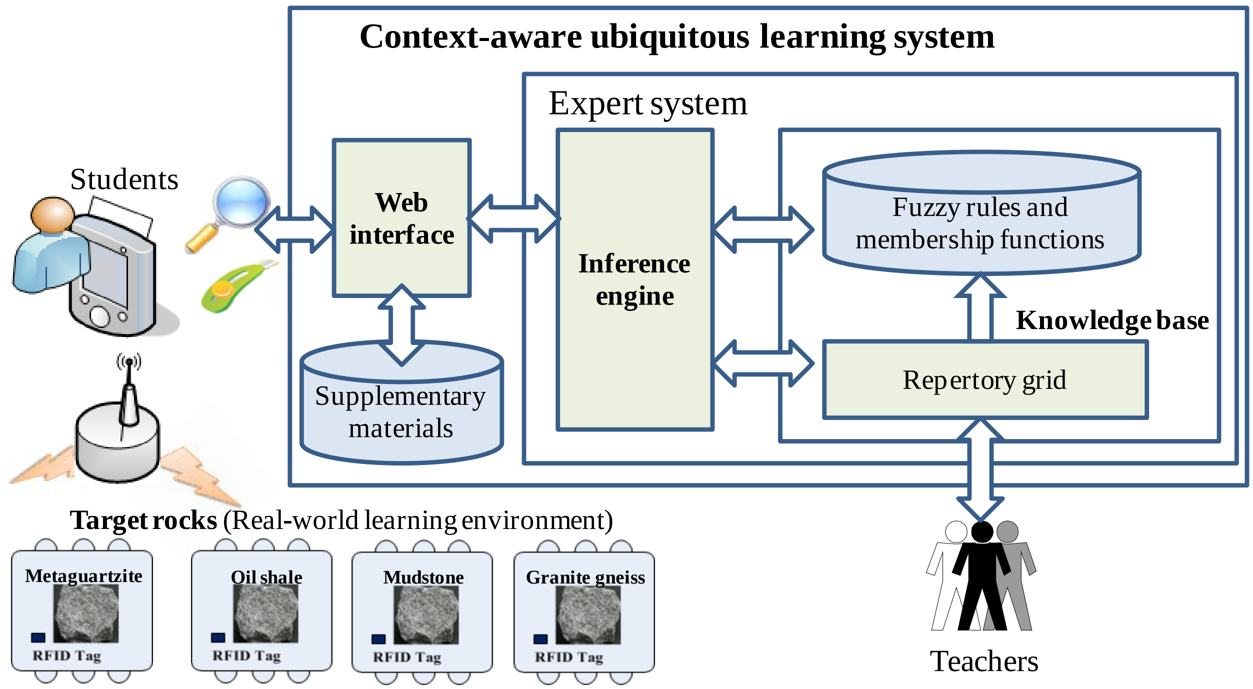

Figure 1. Structure of the expert system-based context-aware ubiquitous learning environment

Before a learning activity, domain experts (i.e., experienced teachers) are asked to provide the knowledge for identifying the learning targets by employing the repertory grid approach. The elicited knowledge is then used for guiding the students to construct their own repertory grids and to clarify some misconceptions during the learning process. Table 1 shows an illustrative example of a partial repertory grid developed by the teachers, which contains the knowledge for distinguishing a set of rocks that are often used to identify geological age for learning about the Earth's history and processes.

Table 1. Illustrative example of a repertory grid with k = 5

	Granite gneiss	Oil shale	Mudstone	Gabbro	Serpentinite	
Highly Crystallized	1	5	5	1	1	Not crystallized
Highly hard	1	3	5	2	1	Not hard
Highly glossy	2	5	5	4	5	Not glossy
Highly Laminated	5	1	2	5	5	Not laminated

In addition to the original repertory grid provided by the domain experts, the content of the grid is transferred to a set of fuzzy rules based on the procedure proposed by Tseng and Wu (2007), that is, a rule is generated from each column of the repertory grid by using High, More or less high, Average, More or less low and Low to represent the rating values 1, 2, 3, 4 and 5, respectively. For example, from the first column of Table 1, the following rule is generated:

R_{01}: IF the Crystallized degree is High
AND the hardness degree is High
AND the glossy degree is More or less high
AND the Laminated degree is Low
THEN the target rock is likely to be Granite gneiss.

The membership functions for Low, Average and High are defined as follows:

$$LOW(x;\alpha,\beta,\gamma) = \begin{cases} 1 & \text{for } x \le \alpha \\ 1-2(\frac{x-\alpha}{\gamma-\alpha})^2 & \text{for } \alpha \le x \le \beta \\ 2(\frac{x-\gamma}{\gamma-\alpha})^2 & \text{for } \beta \le x \le \gamma \\ 0 & \text{for } x \ge \gamma \end{cases}$$

$$AVERAGE(x;\alpha,\beta,\gamma) = \begin{cases} 0 & \text{for } x \le \alpha \\ 2(\frac{x-\alpha}{\beta-\alpha})^2 & \text{for } \alpha \le x \le \frac{(\alpha+\beta)}{2} \\ 1-2(\frac{x-\beta}{\beta-\alpha})^2 & \text{for } \frac{(\alpha+\beta)}{2} \le x \le \beta \\ 1-2(\frac{x-\beta}{\gamma-\beta})^2 & \text{for } \beta \le x \le \frac{(\beta+\gamma)}{2} \\ 2(\frac{x-\gamma}{\gamma-\beta})^2 & \text{for } \frac{(\beta+\gamma)}{2} \le x \le \gamma \\ 0 & \text{for } x \ge \gamma \end{cases}$$

$$HIGH(x;\alpha,\beta,\gamma) = \begin{cases} 0 & \text{for } x \le \alpha \\ 2(\frac{x-\alpha}{\gamma-\alpha})^2 & \text{for } \alpha \le x \le \beta \\ 1-2(\frac{x-\gamma}{\gamma-\alpha})^2 & \text{for } \beta \le x \le \gamma \\ 1 & \text{for } x \ge \gamma \end{cases}$$

In these membership functions, the parameters α, β and γ are determined by the domain experts based on the characteristics of the target elements. For example, assume that the values of hardness degree range from 0 to 1.0, α, β and γ could be 0, 0.5, 1.0, respectively.

Based on the knowledge provided by the domain experts (i.e., teachers), the context-aware ubiquitous learning system is able to evaluate whether the students can correctly identify the target rocks by comparing their answers with those of the expert system.

Figure 2 shows how the learning system guides the students to complete their learning tasks. In each learning stage, the student is asked to walk toward the specified learning target and sense the tag on the target with the RFID reader on the mobile device. Once the learning system has confirmed the location of the student, it starts to state the learning tasks and guide the student to observe the target based on the knowledge provided by the teacher. If the student fails to correctly collect a datum for describing some features (e.g., the distance between the student's input value and the corresponding value in the objective grid is greater than θ = (k-1)/2; that is, they are in different poles of the grid), the learning system will guide the student to observe a comparative target to better understand that feature. Following that, the learning system will ask the student to go back to the current target to collect the datum again.

Consider the illustrative example given in Table 1; assuming that Mudstone is the current target, it should be "not crystallized" (with a rating value of 5); however, the value given by the student is 2, which represents "crystallized." For the 5-scale rating mechanism, θ = (5 - 1)/2 = 2. In this case, the distance between the input value and the corresponding value in the objective grid is 5 - 2 = 3, which is greater than θ = 2. In this case, the learning system judges that the student has difficulty in identifying the feature "crystallized," and hence guides the student to observe a comparative rock that is "crystallized" to clarify the misconception. After making the comparison, the student is asked to input the value again. Once the student has correctly identified the feature, the learning system guides him/her to identify the next feature of that rock. The learning activity is completed when all of the features of each target rock have been correctly identified.

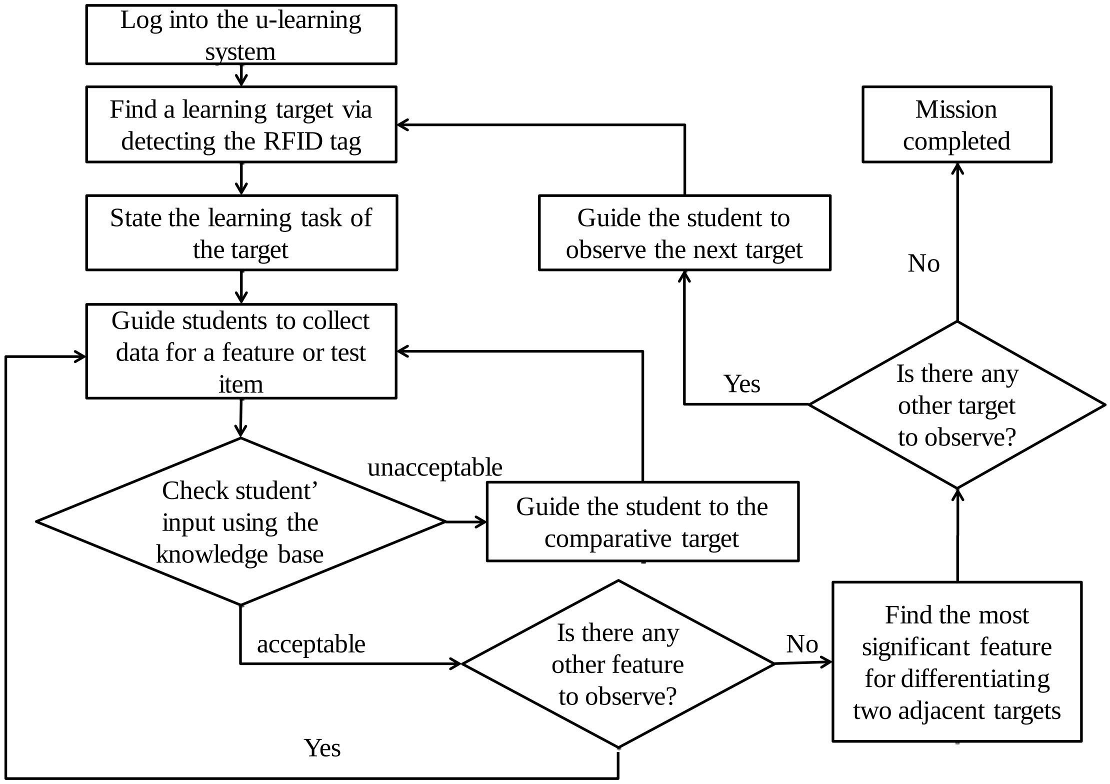

Figure 2. The learning guidance procedure

In addition to helping the students collect data based on observations, the learning system also guides them to collect data from the learning targets. For example, Figure 3 shows how the context-aware ubiquitous learning system guides a student to test the hardness of the target rock in a Geosciences learning activity. The student is asked to use the knife to scratch the rock, and then use the magnifying glass to observe the surface of the rock.

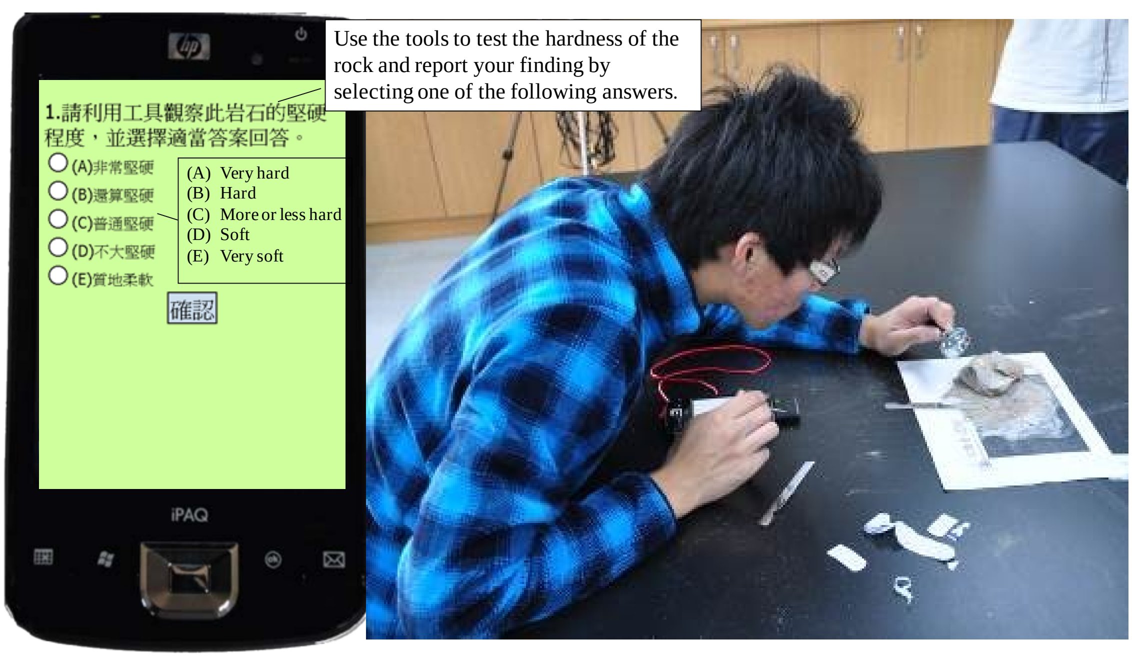

Figure 3. Example of guiding the student to test the hardness of a rock

Furthermore, the learning system will guide the student to observe and record every feature of the target, and then those of the next target. During the learning activity, the students are arranged to observe the targets and collect data in a “most similar-first” sequence; that is, any two adjacent targets that the students observe have the most similar features. Consequently, the learning system will ask the students to compare the features of two adjacent targets once the observation and data collection tasks for the two targets are completed. For example, Figure 4 shows the context-aware ubiquitous learning system interface for guiding the students to find the most significant feature that can be used to differentiate two rocks, that is, Mudstone and Oil shale.

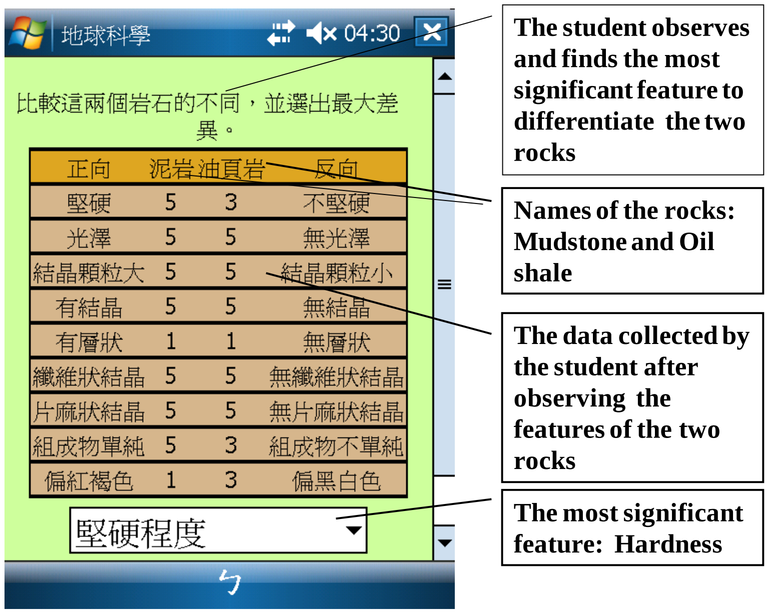

Figure 4. Example of comparing the features of two rocks

After the students have completed the observations and data collection for all of the learning targets, the learning system depicts the collected data to the students, with which the students can make an overall review of the learning targets; moreover, they can have an integrated view of the similarities and differences between the targets. Following that, an in-field assessment is conducted to evaluate whether the students have the competence to identify the target rocks based on what they have observed and learned during the learning activity. The learning system guides individual students to each learning target and asks them to identify it. The answers given by the students are evaluated by the expert system. For those incorrect answers, feedback is given by showing the “correct” and “incorrect” elements with the ratings of each construct to help the students make reflections.

Experiment design

Based on the proposed approach, an experiment was conducted on a senior high school Geosciences course. The objective of this learning activity was to train the students to identify and differentiate the features of a set of target rocks (i.e., Metaguartzite, Oil shale, Mudstone, Granite gneiss, Granite, Diorite, Serpentinite, Gabbro and Conglomerate), which has been recognized as an important and fundamental topic for understanding the Earth’s history and processes (Kortz & Murray, 2009). It should be noted that the learning activity was part of the existing curriculum of the sample school; that is, the learning activity conducted in this study reflected the teaching reality of that school.

The real-world learning environment is a science laboratory, in which each target rock is labeled with an RFID tag, and each student is equipped with a set of tools, including a mobile device with an RFID reader, a knife and a magnifying glass. The learning system first presents the learning task via the mobile device and then checks the location of individual students via the RFID reader. Once the student is near the target rock, the learning system starts to guide the students to observe the rock based on the features pre-defined by the teacher. The student can use the knife to scratch the surface of the rock to test its hardness, observe the color, shape and size of the rock, and touch the rock to feel its surface granular structure. Moreover, the student can also use the magnifying glass to more closely observe the crystallized, glossiness and laminated degrees of the rock.

During the learning process of identifying rocks, the students need to collect various data concerning the rocks (e.g., color, shape, texture, transparency and hardness) via observing the surface and detecting the physical properties of the rocks (Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005). Like other science courses, the aim of the subject unit is to engage students in "focusing" on important features of the learning targets (i.e., the rocks) and "selecting" proper features for "discriminating" and "distinguishing" the targets via conducting contextualized inquiry-based learning activities (Bloom, 1994; Feletti, 1993; Levy, Aiyegbayo, & Little, 2009; Li & Lim, 2008).

Participants

The participants of this experiment were 58 tenth grade students from two classes of a senior high school in Tainan County, Taiwan. One class with 30 students, including 20 males and 10 females, was assigned to be the experimental group. The other class with 28 students, including 20 males and 8 females, was the control group. All of the students were taught by the same teacher who had more than 5 years experience teaching the Geosciences course.

Experiment procedure

As shown in Figure 5, the students in the experimental group were guided to learn with the Geosciences context-aware ubiquitous learning system with the proposed repertory grid-oriented guiding mechanism. Both groups of students were equipped with a knife and a magnifying glass during the learning activity.

During the learning activity, the Geosciences context-aware ubiquitous learning system guided the students in the experimental group to observe and compare the target rocks. Moreover, they were asked to collect data related to the current target rock via observations, touching or even using the knife to test the hardness of the rock. Furthermore, the learning system would invoke the expert system to evaluate whether the students were able to correctly identify the target rocks and gave them hints or guides them to make further observations if their answers were incorrect.

On the other hand, the students in the control group learned with the conventional context-aware u-learning approach, in which the learning system presented the same learning tasks to the students, guided them to observe the target rocks, and provided the same supplementary materials to them for completing the learning missions. In each learning stage, the students were also asked to collect data of the current target rock for completing the learning sheet via observations, touching or using the knife to test the hardness of the rock.

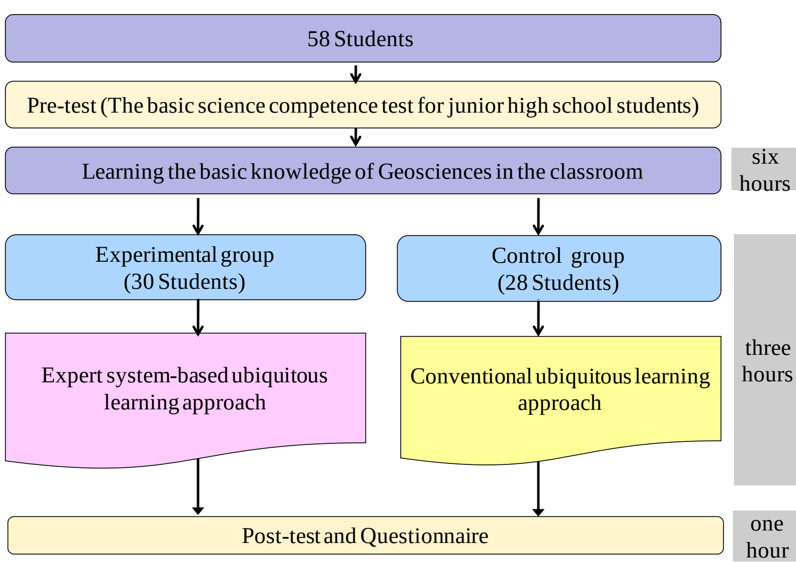

Figure 5. Experiment procedure

Measuring tools

The pre-test aimed to evaluate the basic Geosciences knowledge of the students before participating in the learning activity. It consisted of 40 multiple choice items with a perfect score of 80. The post-test aimed to test the students' competences for identifying and differentiating the target rocks. It consisted of 24 multiple choice items with one point per item, including 5 items for the "Remember" category, 4 items for the "Understanding" category, 3 items for the "Apply" category, 7 items for the "Analysis" category, and 5 items for the "Evaluate" category, based on the revised Bloom's taxonomy of educational objectives (Anderson & Krathwohl, 2001). All of the test items were developed by two teachers who had more than 5 years experience teaching the course, and were verified by a researcher who had more than 20 years experience in developing test items.

The learning attitude and technology acceptance questionnaire originated from the questionnaire developed by Chu, Hwang, Tsai, and Tseng (2010). It consisted of 19 items with a six-point Likert rating scheme, including 6 items for "Learning attitude toward Natural science," 5 items for "Perceived usefulness" and 7 items for "Perceived ease of use." The Cronbach's alpha values of the questionnaire and the three dimensions were 0.94, 0.9, 0.95 and 0.94, respectively.

Experimental results and discussion

In this study, a context-aware u-learning environment for Geosciences courses was developed by providing an interactive guiding mechanism to help students recognize and differentiate the target rocks in the real world. In this section, the experimental results are presented and discussed in terms of the dimensions of learning achievement, Bloom's taxonomy of educational objectives, perceived ease of use and perceived usefulness of using the context-aware ubiquitous learning system, as well as learning attitudes toward the Geosciences course.

Learning achievements

Before participating in the learning activity, the students took a pre-test, which aimed to evaluate their prior knowledge for learning the subject unit. The means (SDs) of the experimental group and the control group were 77.56 (1.94) and 76.71 (2.19), respectively. The t-test result of the pre-test scores of the two groups showed no significant difference ($t = 1.57$, $p > .05$), implying that the two groups of students had equivalent prior knowledge before participating in the learning activity.

To evaluate the performance of the context-aware ubiquitous learning system, ANCOVA was used to exclude the difference between the prior knowledge of the two groups by using the pre-test scores as the covariate and the post-test scores as the dependent variable. Table 2 summarizes the ANCOVA results, in which the adjusted mean values of the post-test scores were 17.94 for the experimental group, and 13.67 for the control group; moreover, a significant difference was found between the two groups with $F = 47.12$ and $p < .05$, implying that the context-aware ubiquitous learning system had significantly positive effects on the learning achievements of the students for the Geosciences course.

Table 2. Descriptive data and ANCOVA results of the post-test scores

		N	Mean	S.D.	Adjusted Mean	Std.Error.	*F*
Post-test	control group	28	13.54	2.46	13.67	0.44	47.12^{*}
	experimental group	30	18.07	2.36	17.94	0.43	

$^{*}p < .05$

Bloom's taxonomy of educational objectives

In the Geosciences learning activity, the tasks were arranged to foster the students' various competences concerning the cognitive processes of Bloom's Taxonomy of educational objectives, including "Remember" (e.g., recognizing or identifying the rocks), "Understand" (e.g., illustrating and classifying the rocks), "Apply" (e.g., addressing the usage of the rocks), "Analyze" (e.g., differentiating or distinguishing the rocks) and "Evaluate" (e.g., detecting and testing the features of the rocks) (Anderson et al., 2001; Bloom et al., 1956). Without effective guidance, such a learning scenario might be too complex for the students, in particular, for those higher order cognitive processes, such as "Analyze" and "Evaluate" (Hwang, Chu, Lin, & Tsai, 2011). Therefore, it is worth investigating the effects of the context-aware ubiquitous learning approach on the cognitive processes of Bloom's Taxonomy of educational objectives.

Table 3 shows the ANCOVA results for the two groups' post-test scores of the test items related to the individual cognitive dimensions. It is found that the F values of the "Remember," "Apply," "Analyze" and "Evaluate" dimensions are 6.10, 6.10, 6.14 and 44.21, respectively, with $p < .05$. Moreover, the average scores of the experimental group (i.e., 3.63, 2.73, 5.27 and 2.70) are higher than those of the control group (i.e., 2.79, 2.21, 3.18 and 1.82), implying that the learning achievements of the experimental group are significantly better than those of the control group in these four dimensions. Consequently, it is concluded that the context-aware ubiquitous learning approach with the interactive guidance mechanism can benefit the students in enhancing their learning performance, including those higher order thinking competences such as "Analyze" ($F = 44.21$ and $p < .05$) and "Evaluate" ($F = 7.15$ and $p < .05$).

Table 3. ANCOVA results for the post-test scores of the individual cognitive dimensions

		N	Mean	S.D.	Adjusted Mean	Std. Error.	*F*	*d*
Remember (5 points)	control group	28	2.79	1.33	2.80	0.24	6.10*	0.64
	experimental group	30	3.63	1.30	3.61	0.24		
Understand (4 points)	control group	28	3.54	0.69	3.54	3.30	1.36	0.31
	experimental group	30	3.73	0.52	3.71	3.50		
Apply (3 points)	control group	28	2.21	0.88	2.26	0.13	6.14*	0.74
	experimental group	30	2.73	0.45	2.70	0.12		
Analyze (7 points)	control group	28	3.18	1.25	3.19	0.22	44.21*	1.81
	experimental group	30	5.27	1.05	5.25	0.21		
Evaluate (5 points)	control group	28	1.82	1.02	1.88	0.21	7.15*	0.79
	experimental group	30	2.70	1.18	2.65	0.20		

*$p < .05$

Perceived ease of use and usefulness of the context-aware ubiquitous learning system

To better understand the students' perceptions of the use of the context-aware ubiquitous learning system, this study also collected the students' feedback in terms of "perceived usefulness" and "perceived ease of use," as shown in Table 4. It is found that most students gave positive feedback concerning the two dimensions of the context-aware ubiquitous learning system. The average ratings for "perceived usefulness" are 4.59 and 4.42 for the experimental group and the control group, respectively; moreover, their average ratings for "perceived ease of use" are 4.38 and 4.51, implying that the context-aware ubiquitous learning system has been well accepted by the students. However, in comparison with the ratings given by the control group, it should be noted that the students in the experimental group gave higher ratings to "perceived usefulness," while giving lower ratings to "perceived ease of use."

By applying the t-test to the ratings given by the two groups, significant differences were found between the ratings for the items "I do not need to put in lots of effort during the context-aware ubiquitous learning activity" and "It is not difficult to use the context-aware ubiquitous learning system," indicating that, in comparison with the control group, the students in the experimental group put in more effort during the learning activity and felt that using the context-aware ubiquitous learning system was not very easy. Moreover, the experimental group also gave lower average ratings for the items "It is very easy to work with the interface of the context-aware ubiquitous learning system" and "Generally speaking, the context-aware ubiquitous learning system is easy to use" than those given by the control group. It can be seen that, on average, the use of the mobile devices is not difficult for the students, but the design of the user interface can be improved, in particular, for the context-aware ubiquitous learning system with the interactive guiding approach.

In terms of perceived usefulness, the items "The context-aware ubiquitous learning system is helpful to me in learning new knowledge" and "Using a PDA to learn and observe the learning targets in the real world is helpful to me" received the highest average rating from the experimental group, implying that most students in the experimental group identified the usefulness of the context-aware ubiquitous learning approach for guiding them to learn in the real world. It should be noted that, for the item "The context-aware ubiquitous learning system provides a more convenient learning environment," the experimental group gave a lower average rating (4.43) than that of the control group (4.54). This result is consistent with those findings concerning "perceived ease of use."

Table 4. Questionnaire results about perceived ease of use and usefulness of the context-aware ubiquitous learning system

Dimension	Questionnaire item	Group	mean	S.D.	*t*
Perceived Usefulness	The context-aware ubiquitous learning system provides a convenient learning environment.	Control	4.54	0.96	0.29
		Experiment	4.43	1.61	
	The context-aware ubiquitous learning system is helpful to me in learning new knowledge.	Control	4.50	0.75	-0.84
		Experiment	4.73	1.28	
	The use of sensing technology has smoothed the context-aware ubiquitous learning process.	Control	4.04	1.00	-0.81
		Experiment	4.30	1.44	
	Using a PDA to learn and observe the learning targets in the real world is helpful to me.	Control	4.71	0.85	-0.78
		Experiment	4.93	1.23	
	I feel that I can learn better with this context-aware ubiquitous learning approach.	Control	4.32	1.02	-0.07
		Experiment	4.53	1.28	
Perceived Ease of Use	It is not difficult to use the context-aware ubiquitous learning system.	Control	5.32	0.67	2.47*
		Experiment	4.73	1.08	
	I do not need to put in lots of effort during the context-aware ubiquitous learning activity.	Control	4.61	0.99	3.42*
		Experiment	3.53	1.36	
	The context-aware ubiquitous learning content is easy to understand.	Control	4.32	0.99	-0.05
		Experiment	4.33	1.03	
	I learned how to use the context-aware ubiquitous learning system quickly.	Control	5.00	0.72	-0.48
		Experiment	5.10	0.84	
	During the learning activity, operating the PDA is not difficult for me.	Control	5.04	0.79	-0.29
		Experiment	5.10	0.88	
	It is very easy to work with the interface of the context-aware ubiquitous learning system.	Control	3.71	1.12	-1.04
		Experiment	3.37	1.40	
	Generally speaking, the context-aware ubiquitous learning system is easy to use.	Control	4.97	0.92	1.22
		Experiment	4.63	1.13	

Learning attitudes toward Geosciences

Table 5 shows the students' feedback concerning their learning attitudes toward Geosciences. It is found that the students in the experimental group showed better learning attitudes than those in the control group; in particular, for the items "I would like to learn more about the rocks in the real world environment" and "I would like to observe the real-world targets of Geosciences," which showed significant differences between the average ratings given by the two groups. Consequently, it can be seen that the provision of an interactive guiding mechanism in the real-world environment is important for improving the learning attitude of students.

Table 5. Questionnaire results about learning attitudes toward Geosciences

Questionnaire item	Group	Mean	S.D.	*t*
I like to learn to identify and differentiate the rocks after participating in this learning activity.	Control	4.46	0.96	-0.64
	Experiment	4.67	1.40	
I would like to learn more about the rocks in the real world environment.	Control	4.54	0.96	-2.47*
	Experiment	5.17	0.99	
It is important to learn to differentiate the rocks.	Control	4.32	0.98	-1.32
	Experiment	4.70	1.18	
I would like to observe more real-world targets of Geosciences.	Control	4.82	0.86	-3.38*
	Experiment	5.57	0.82	
I will actively search for more information and learn about	Control	4.50	0.92	-1.26

Geosciences.	Experiment	4.87	1.25	
It is important for everyone to take the Geosciences course.	Control	4.11	0.92	-1.24
	Experiment	4.47	1.25	

Conclusions

In this study, an expert system was developed to support context-aware ubiquitous learning activities for science courses. An experiment was conducted in a Geosciences course to help students recognize and differentiate the target rocks in a laboratory. The experimental results showed that the students' learning achievements were significantly improved in terms of several cognitive processes in Bloom's taxonomy of educational objectives with the assistance of this real-world learning guidance approach. Moreover, it is found that the experimental group students had significantly better learning achievement than the control group students in the "Remember," "Apply," "Analyze" and "Evaluate" dimensions, while no significant difference was found between the two groups in the "Understand" dimension.

As the grid-based interactive guiding mechanism can be seen as a Mindtool that assists students to collect and organize what they have observed and learned in the real world, such findings conform to what has been reported in previous studies, namely that computerized Mindtools are able to engage students in higher order thinking, such as "Analyze" and "Evaluate" (Chu, Hwang, & Tsai, 2010; Jonassen, 2000). In particular, the students' learning performance related to the "Analyze" category reveals a rather large effect size, showing that the use of Mindtools in such a context-aware u-learning environment is helpful to the students in improving their analysis performance (Cohen, 1988, 1992). Furthermore, researchers have found that representing knowledge in grids makes it easy to examine and interpret the structure and logic of the knowledge as well as to recognize the differences between the targets (Cragun & Steudel, 1987; Hwang, Chu, Lin, & Tsai, 2011); therefore, the findings of this study concerning those four dimensions are reasonable. In terms of the "Understand" dimension, the difference between the two groups is not significant since both groups of students have been situated to learn in the real-world environment with access to digital supplementary materials. Researchers have pointed out that such an authentic learning approach is helpful to students in understanding the concepts to be learned (Arnseth, 2008; Hwang, Yang, Tsai, & Yang, 2009; Resnick, 1987); that is, the students' performance concerning the "Understand" dimension could mainly be affected by the real-world environment in which they have been situated.

Although the performance of the learning system is desirable, it should be noted that the PDAs used in this study cannot represent modern mobile technology. In fact, modern mobile technology is no more a byproduct of desktop technology as was the case with PDAs that mimicked desktop and laptop behavior. New mobile devices, such as iPads and Android Pads, not only deviate from the established PC world, but also tend to integrate and interconnect with users in such a manner that cannot be reached by simple PDAs. Therefore, it is worth adapting the proposed approach of this study to modern mobile technology. Furthermore, there are several extended issues of this study to be investigated. First, the real-world learning behaviors of the students have not been fully recorded and analyzed; therefore, it is worth investigating the real-world learning patterns of the students and the relationships between the learning patterns and the learning achievements. Second, it is worth applying this approach to other subject units to evaluate its effectiveness in depth. Third, for those learning subjects that are not concerned with differentiating knowledge, it is worth developing new learning guidance mechanisms or Mindtools to help students improve their learning effectiveness. Third, one limitation of this study is that PDAs are not as popular and powerful (in terms of user interface, screen resolution, memory size and CPU performance) as those modern mobile platforms, such as iOS or Android; therefore, it remains a challenging issue to implement such an approach on the modern mobile devices (e.g., smartphones and tablet personal computers) with new sensing technologies, such as the QR (Quick Response) code, in the future.

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