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A knowledge acquisition approach to developing Mindtools for organizing and sharing differentiating knowledge in a ubiquitous learning environment

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ABSTRACT

Previous studies have reported the importance and benefits of situating students in a real-world learning environment with access to digital-world resources. At the same time, researchers have indicated the need to develop learning guidance mechanisms or tools for assisting students to learn in such a complex learning scenario. In this study, a grid-based knowledge acquisition approach is proposed and a Mindtool is developed to help students organize and share knowledge for differentiating a set of learning targets based on what they have observed in the field. An experiment has been conducted in an elementary school Natural Science course for differentiating different species of butterflies. Forty-one fifth-grade students have been assigned to a control group and an experimental group to compare the effect of the conventional approach and that of the proposed approach. The experimental results show that the proposed approach not only improves students' learning achievements, but also significantly enhances their ability of identifying species in the field.

1. Introduction

Many educators have emphasized the importance and necessity of "authentic activities" if effective learning is to take place (Collins, 1991; Looi et al., 2010; Resnick, 1987; Price & Rogers, 2004). Researchers have indicated that the context of authentic activities could be seriously lost in traditional teaching in classroom settings; consequently, the students might not be able to learn in a meaningful way, and their competence for using knowledge to deal with real-world problems could be disappointing (Arnseth, 2008; Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Furthermore, various studies have shown the value of conducting learning and assessment activities in real-world environments (Chu et al., 2008; Looi et al., 2009).

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 (Minami, Morikawa, & Aoyama, 2004). In recent years, several studies have been conducted to demonstrate the usage of mobile and wireless communication technologies in supporting authentic learning. Chen, Kao, and Sheu (2003) reported a mobile learning system for scaffolding students' learning about bird watching using hand-held devices. Chen, Chang, and Wang (2008) presented a learning environment to scaffold learners with mobile devices and sensor techniques. With the help of these new technologies, individual students are able to learn without being limited by space and time; therefore, "ubiquitous learning" or "u-learning" has become a widely discussed educational issue (Chen, Hwang, Yang, Chen, & Huang, 2009; Joiner, Nethercott, Hull, & Reid, 2006; Jones & Jo, 2004; Lin, 2007; Ogata & Yano, 2004).

In this paper, the term "context-aware u-learning" defined by Hwang, Tsai, and Yang (2008) is used to represent the learning approach of our study. In a context-aware u-learning environment, individual students are equipped with a mobile device with the wireless communication facility, so that the learning system on the server can interact with the student via the mobile device. Moreover, sensing devices (e.g., Radio Frequency Identification, RFID) are installed in the learning environment, such that the learning system can detect the location of individual students and guide them to learn in the real world accordingly. Such a technology-enhanced learning model not only supports learners with an alternative way of dealing with problems in the real world, but also enables the learning system to more actively interact

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with the learners (Hwang, Kuo, Yin, & Chuang, 2010; Hwang, Tsai, & Yang, 2008; Hwang, Yang, Tsai, & Yang, 2009; Yang, Okamoto, & Tseng, 2008).

However, without proper support or guidance, the new learning scenario might confuse the students owing to its complexity and richness (Chu, Hwang, & Tsai, 2010; Hwang, Kuo, Yin, & Chuang, 2010), in particular, for those higher order cognitive processes in Bloom's taxonomy of educational objectives, such as "analyze", "evaluate" and "create" (Bloom et al., 1956; Anderson et al., 2001). In this study, we aim to foster students' abilities in "differentiating" knowledge, which has been categorized by Anderson et al. (2001) as being an "analyze" competence including the cognitive processes of "focusing", "selecting", "discriminating" and "distinguishing". The students need to determine a set of features or attributes in order to differentiate the learning targets based on their observations in the field and to collect data to identify the learning targets. That is, they need to learn the abilities of "focusing" on important features of the learning targets and "selecting" proper features for "discriminating" individual targets and "distinguishing" those targets.

Technology tools to aid students' construction of knowledge, that is to assist learners to interpret and organize their knowledge, are seen as an important way forward (Chiou, Tseng, Hwang, & Heller, 2010; Chu, Hwang, Tsai, & Tseng, 2010; Hwang & Chang, 2011). Jonassen, Carr, and Yueh (1998, p.1) formally defined such Mindtools 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."

There are several computer systems that can serve as Mindtools, such as database systems (i.e., the systems that facilitate students to store and utilize the collected data), spreadsheets (i.e., the systems that help students analyze the relationships among numbers and math formulas), semantic networks (e.g., concept maps), hypermedia construction systems, simulation systems, knowledge acquisition systems (i.e., the systems that assist people in developing well-organized knowledge bases), and computer conferencing systems (Valcke, Rots, Verbeke, & Braak, 2007). In this study, we mainly focus on developing a Mindtool to help elementary school students organize and share knowledge for differentiating learning targets in a ubiquitous learning environment for natural science courses; therefore, some of these well-known Mindtools, including concept maps, database and knowledge acquisition systems, seem to be good choices for this study. However, in this learning activity, the students need to determine a set of features or attributes for differentiating the learning targets as well as collecting data for identifying the learning targets in the field, which makes the concept map and database system approaches not as suitable as the knowledge acquisition system approach. Concept Maps would be a good choice if the learning objective is to find the relationships between the learning targets (or concepts) instead of finding their similarities and differences; moreover, database systems are more suitable for collecting data based on a set of pre-defined attributes. Consequently, a knowledge acquisition system which is able to assist students in determining traits or attributes for differentiating the collected data as well as organizing the knowledge, could be the most promising choice.

Among the existing knowledge acquisition methods, the grid-based approach, such as the *repertory grid* method proposed by George Kelly (1955), has been recognized as being an effective and widely used tool for eliciting knowledge for differentiating a set of learning targets (Chu & Hwang, 2008; Edwards, McDonald, & Young, 2009; Jankowicz, 2004; Shih et al., in press). Researchers have indicated that representing knowledge in grids makes it easy to inspect and analyze the organization and logic of the knowledge (Cragun & Steudel, 1987); in addition, the visual metaphor of grids amplifies individuals' ability to recognize the distinctions between the targets (Ford, Petry, Adams-Webber, & Chang, 1991). Consequently, in this study, a grid-based method is employed instead of other knowledge acquisition methods, such as decision trees and flow charts (Hwang, Chu, Shih, Huang, & Tsai, 2010), since the developed tool is going to be used by elementary school students who might have difficulty in using systems with complex notions and procedures.

In this paper, we present the design and development of a Mindtool, which has been evaluated in a learning activity conducted in an elementary school natural science course by investigating the following research questions:

(1) Do the students who learn with the Mindtool in the context-aware u-learning environment have better learning achievement than those who learn with the conventional u-learning approach?
(2) Compared to the conventional u-learning, does the use of the Mindtool for knowledge organizing and sharing improve the field "differentiating" competence of the students?

2. Development of learning environment and Mindtool

2.1. Context-aware ubiquitous learning environment

There could be various contexts (e.g., locations, temperature or humidity) detected and sensing devices (e.g., RFID, Global Positioning System (GPS) or Infrared Ray System) used in a context-aware u-computing environment, depending on the requirements of the learning activities. For example, RFID is suitable for detecting contexts in smaller areas owing to the cost consideration, while GPS is suitable for detecting locations in a large area because of the accuracy consideration. Moreover, among various contexts that can be sensed, researchers have indicated that "timely location" is the most important and fundamental parameter for context-aware u-learning (Chu & Hwang, 2010; Hwang, Tsai, & Yang, 2008) since most of the environmental contexts can be determined if the location of the students is known.

Fig. 1 shows the notion of a context-aware u-learning environment for this study, which is a real-world environment in which each learning target is labeled with an RFID tag. Meanwhile, each student has a hand-held mobile device (i.e., PDA) equipped with an RFID reader. In the learning area, wireless communication is available, so that the mobile device can communicate with the computer server that executes the learning system and the Mindtool. When a student moves around the learning area, the RFID reader on the mobile device can detect the signal (identification information for learning targets) from the tag on the learning target that is nearest to the student. The detected signal is then transferred from the mobile device to the learning system via wireless communication, so that the learning system is able to identify the location of the student at that moment and provide further guidance or instructions accordingly.

Fig. 2 shows an illustrative example of guiding the students to find the target object, the "*Eurema hecabe*" butterfly, in the butterfly ecology garden. By following the instructions, the students can find the exact location of the target butterfly, and start to observe its characteristics.

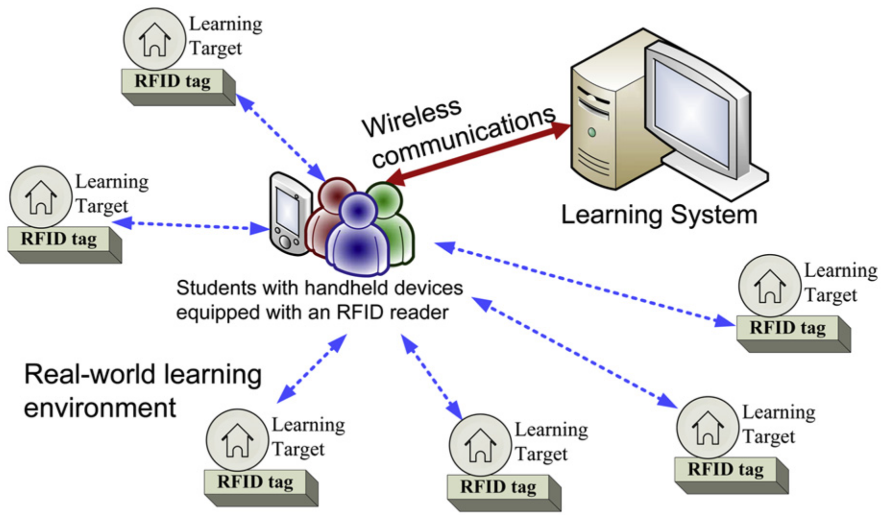

Fig. 1. The context-aware u-learning environment.

2.2. *Mindtool for organizing and sharing “differentiating” knowledge*

The objective of this study is to develop a Mindtool to engage students in building and sharing knowledge for differentiating a set of learning targets, which has been recognized as being an important science competence for children (Cartwright, 2002).

A repertory grid-like approach with multiple data types is used to develop the Mindtool for building and sharing knowledge in a u-learning environment. A single repertory grid is represented as a matrix whose columns have element labels and whose rows have construct labels. An element might represent a decision to be made, an object to be classified or a goal to be achieved, while a construct consists of a trait and the opposite of that trait; therefore, a grid represents a class of objects, or individuals, and the value assigned to an element-construct pair value reflects the linking relationship of the element and the construct. Kelly (1955, p. 61) defined the notion of personal construct as “In its minimum context a construct is a way in which at least two elements are similar and contrast with a third.” This notion has become an important step for developing a repertory grid.

In a conventional repertory grid, a 5-scale rating mechanism is usually used to represent the relationships between the elements and the constructs; that is, 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

Fig. 2. Illustrative example of guiding the student to observe the target butterfly.

(Chu & Hwang, 2008; Chu, Hwang, & Tseng, 2010). However, in practical applications, the features for describing the elements (i.e., learning objects) are often too complex to be represented with this rating scheme; therefore, several extensions have been made owing to the need to enhance its knowledge representation ability. For example, Castro-Schez, Jennings, Luo, and Shadbolt (2004) proposed a fuzzy repertory grid for acquiring the finite set of attributes or variables that the expert uses in a classification problem, characterizing and discriminating a set of elements; Hwang (1995) extended the repertory grid technique to the "fuzzy table," in which constructs were fuzzy attributes that could be rated by means of fuzzy linguistic terms from a finite set. Furthermore, several models have been proposed to generate more meaningful rules from the repertory grid-like approaches using a rating scheme with multiple data types, such as the EMCUD method (Hwang & Tseng, 1990) and its extended versions (Chu & Hwang, 2008; Hwang, Chen, Hwang, & Chu, 2006).

In the u-learning activity, the students need to determine the characteristics for describing and classifying the target elements by themselves. Moreover, they need to fill in each < characteristic, element> relationship with a description instead of a rating; consequently, a repertory grid-like approach with multiple data types, including numerical values and symbolic values, is used to develop the Mindtool. To avoid confusing the readers, we shall use the term "knowledge grid" to represent the grid with multiple data types; moreover, the term "characteristic" is used to replace "construct". In the context of describing butterflies for identification purposes, consider the trait "Forewings' Color" in the sixth row of Table 1. The symbolic values for "Pachliopta aristolochiae interpositus", "Papilio polytes" and "Papilio demoleus" are "Deep brown", "Black with white spots on lower edge" and "Black with many white spots", respectively. Moreover, consider the trait "Number of legs" in the first row of Table 1, the numerical values for "female Papilio memnon heronus", "male Papilio memnon heronus" and "Idea leuconoe" are 6, 6 and 4, respectively. Such relationships are difficult to be described via the conventional 5-scale rating scheme.

To assist the students in organizing and sharing knowledge, a Mindtool, MUKS (Mindtool for Ubiquitous Knowledge Sharing), has been developed to assist the students in identifying and classifying learning objects observed in the real world. Following Kelly's (1955) personal construct notion, the MUKS workflow for guiding the students to complete their knowledge grids is given as follows:

Step 1. Show the students the learning targets specified by the teachers, that is, E_1, E_2, …E_n.
Step 2. Follow the characteristic set determining procedure:
- 2.1 Select two learning targets, say E_i and E_j, from the set of learning targets.
- 2.2 Ask the student to observe E_i and E_j and find the most significant characteristic C_r that is not in the current construct set for distinguishing E_i from E_j.
- 2.3 Repeat Steps 2.1 and 2.2 until the characteristic set determining procedure is completely executed.

Step 3. Ask the student to fill in each < learning target, characteristic > description based on the observations.

After the students have completed their characteristic set, MUKS will assist them in completing their knowledge grids by guiding them to observe the learning targets and fill in the <learning target, characteristic > descriptions, as shown in Fig. 3.

After completing the knowledge grids, the students can log into MUKS in the computer room, where a knowledge sharing interface is provided to show the knowledge grids developed by individual students, as shown in Fig. 4. In this interface, all of the knowledge grids are displayed with a grade from five (excellent) to zero stars (poor). After referring to the graded knowledge grids, the students are allowed to modify their own grids via an editing interface of MUKS.

3. Experiment design

To evaluate the efficacy of the MUKS system, an experiment was conducted on the "Butterfly and Ecology" unit of the natural science course of an elementary school in Taiwan.

3.1. Learning environment and targets

In this study, the authentic learning environment is a "Butterfly and Ecology" garden in an elementary school, which is divided into 11 ecology areas according to the specific host plants; moreover, each area has an instructional sign to introduce the butterflies in that area. Note that each species of butterfly requires special host plants as their food; therefore, in each ecology area, the students are able to observe the ecology of the butterflies that have special relevance to the host plants of that area. In the garden, the host plants (representing a specific set of butterflies) are labeled with RFID tags, and each student has a mobile device equipped with an RFID reader. In addition, wireless

Table 1
Illustrative example of a knowledge grid for butterfly identification.

	Pachliopta aristolochiae interpositus	Papilio polytes	Papilio demoleus	Female Papilio memnon heronus	Male Papilio memnon heronus	Idea leuconoe
Forewings' Color	Deep brown	Black with white spots on lower edge	Black with many white spots	White and black long narrow stripes	Deep blue	White with black spots
Hindwings' Color	Black embellished red and white spots	Black	Black with white spots	White with black spots	Shiny blue	White with black spots
Having tails on hindwings	Yes	Yes	No	Yes	No	No
Having cells on Forewings	Yes, one	Yes, one	No	Yes, one	Yes, one	Yes, one
Having cells on hindwings	Yes, one	No	No	No	Yes, one	Yes, more than one
Number of legs	6	6	6	6	6	4
Obvious different pattern between forewings and hindwings	Yes, there are red and white spots on hindwings	Yes, there are white spots on lower edge of forewings	Yes, there are red ocellus on hindwings	No	Yes, there are wavy edges and a row of big black spots on hindwings	No

Fig. 3. MUKS Interface for entering the <learning object, construct > values.

communication is provided so that the mobile device can communicate with the computer server that executes the learning system and MUKS.

3.2. Participants

The participants of this study were two classes of fifth-grade students taught by the same teacher in an elementary school. The average age of the students was 11. After studying the fundamental knowledge of butterflies in a natural science course, one class was assigned to be the control group ($n = 20$) and the other was assigned to be the experimental group ($n = 21$).

3.3. Experiment procedure

It took 6 weeks to conduct the learning activity, as shown in Fig. 5. In the first two weeks, after studying the fundamental knowledge of butterflies in the natural science course, the two classes were assigned to the control group and the experimental group; in the meantime,

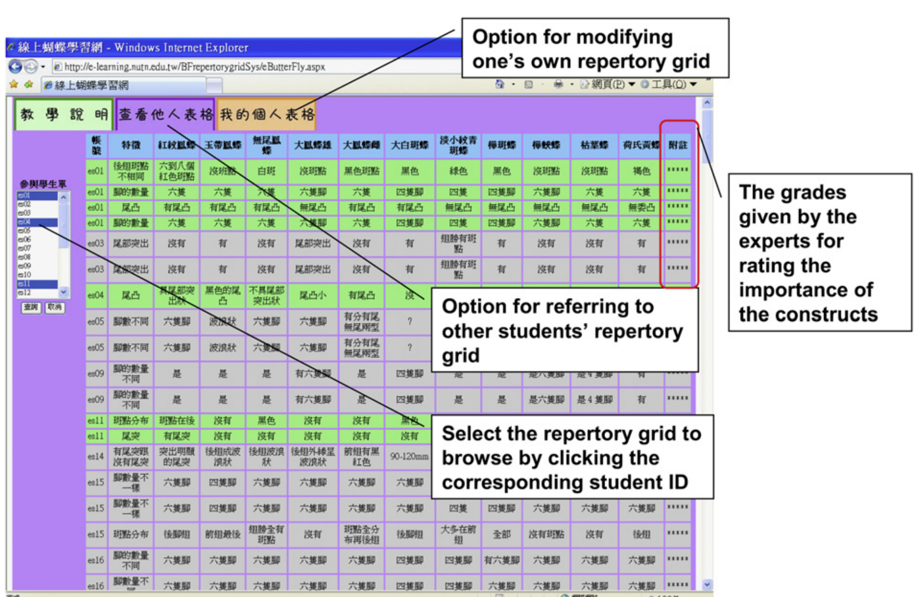

Fig. 4. MUKS Interface for browsing the knowledge grids developed by individual students.

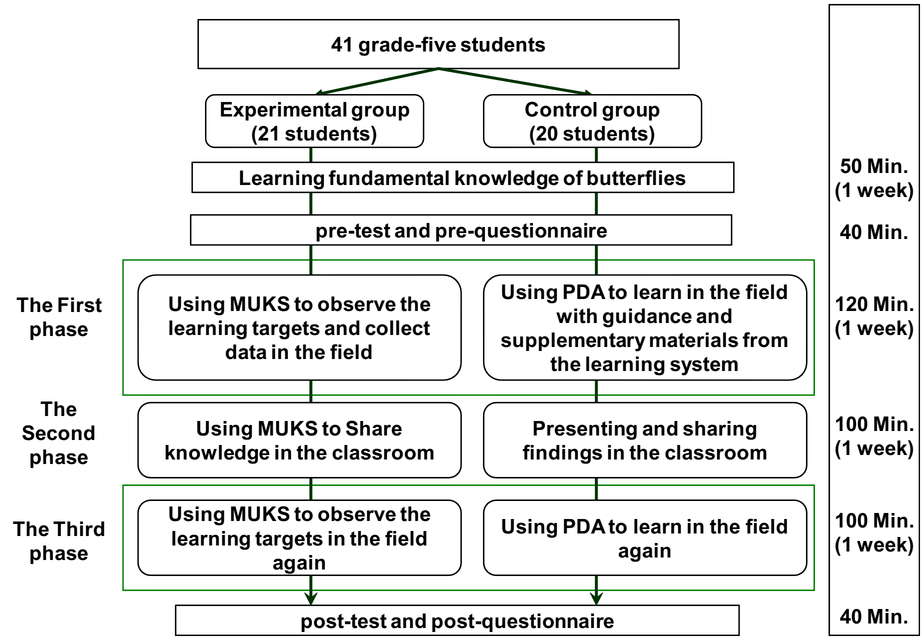

Fig. 5. Experiment design for comparing the proposed approach and the conventional u-learning approach.

the two teachers were trained to grade the knowledge grids according to two dimensions, i.e. one, whether the student can choose the correct observation points, that is characteristics, to distinguish differences between the butterflies, and two, whether the students observed and gave a correct description of the characteristics of the butterflies.

In the 3rd week, the students were asked to take a pre-test with a perfect score of 100. It was a 40-min test for assessing their basic knowledge of butterfly ecology. In the following three weeks (weeks 4–6), the learning activity was conducted in the butterfly ecology garden. Each student was equipped with a PDA to access the hints and supplemental materials from the learning system. Moreover, to avoid the Hawthorne effect, the experimental and the control group students were arranged to learn in different time periods. Therefore, these two groups of students did not have any interaction which might possibly have made them aware of the difference in the treatment. At the end of the 6th week, all of the students took a post-test. It is a 40-min test for assessing the knowledge required to differentiate the butterflies.

As shown in Fig. 5, both the learning activities for the control group and the experimental group consisted of three phases, which are addressed in detail in the following.

3.3.1. Experimental group

In the first phase (week 4, 120 min), the students in the experimental group were guided to observe the learning targets in the butterfly garden, and to compose new knowledge via developing their own knowledge grids by determining the characteristics for describing the learning targets and the relationships among them.

After the students completed their knowledge grids, an integrated knowledge grid was generated by collecting all of the characteristics proposed by the students and sorting them based on the significance scores rated by the teachers. The students were allowed to refer to the integrated knowledge grid as well as individual grids developed by their peers, and to modify their own grids accordingly via the knowledge sharing interface of MUKS in the computer classroom. That is, in the second phase (week 5, 100 min), the students were allowed to incorporate new ideas (characteristics) by discussing with their peers and visiting the integrated knowledge grid.

In the third phase (week 6, 100 min), the students visited the butterfly garden to observe the learning target again, to confirm the revisions they had made in the second phase; moreover, they could modify their own knowledge grids if there were new findings.

Furthermore, the knowledge grids developed by the students in each phase were evaluated by two experienced teachers, who scored each grid based on its structure (the suitability of selecting those characteristics to differentiate the butterflies) and the correctness of the content (the descriptions of the <butterfly, characteristic > relationships). The former represents the students' competence for "focusing" (finding) and "selecting" (adopting) good features for differentiating the learning targets, while the latter represents their ability to "discriminate" and "distinguish" the learning targets in the real world.

3.3.2. Control group

In contrast to the experimental group, the students in the control group learned with the conventional u-learning approach. That is, they were also equipped with a PDA for guiding them to observe each learning target in the butterfly garden; moreover, they could use the PDA to access the supplementary materials via wireless communications.

In the first phase (week 4, 120 min), the students in the control group were guided by the u-learning system to observe the learning targets in the butterfly garden. They needed to complete a worksheet prepared by the teacher based on what they had observed as well as what they had learned from the materials provided by the learning system.

In the second phase (week 5, 100 min), the students were asked to share their experiences in the classroom and discuss with peers their observations about the butterflies. In this phase, the teacher not only chaired the students' presentations for sharing experiences and the peer discussions, but also gave feedback to the students.

In the third phase (week 6, 100 min), the students visited the butterfly garden to observe the learning target again, and to modify their learning sheets accordingly if there were new findings.

3.4. Measuring tools

The measuring tools in this study include the learning achievement test sheets for the pre-test and the post-test and the scoring mechanism for evaluating the quality of the knowledge grids developed by the students. The test sheets were developed by two elementary school teachers who had taught the course for more than ten years. The pre-test aimed to assess the prior knowledge of the students before participating in the learning activity. It consisted of twenty multiple-choice questions (80%) and five fill-in-the-blank questions (20%) about the basic knowledge of butterfly ecology. The post-test aimed to evaluate the students' knowledge for distinguishing butterflies after the learning activity. It consisted of fifteen multiple-choice questions (45%), five matching test items (15%), and ten short answer questions (40%) concerning the identification and classification of butterflies. All of the test items had been validated by a domain expert who had more than twenty years experience in teacher education at the elementary school level and had engaged in developing teaching materials for butterflies and ecology courses.

To evaluate the quality of the knowledge grids developed by the students, this study employed a mechanism for scoring the students' knowledge grids based on the notions and evaluation method proposed by previous studies (Chu, Hwang, & Tsai, 2010). Researchers have indicated that the quality of differentiating a set of elements highly depends on two factors: first, the constructs (i.e., characteristics) used for identifying and classifying the elements (i.e., butterflies); second, the ratings (i.e., descriptions) given to describe the relationships between the constructs and the elements (Chu & Hwang, 2008; Shaw, Turvey, & Mace, 1982). During the learning activity, the students were asked to determine eight characteristics for differentiating the learning targets. Each characteristic proposed by the student was rated with a score ranging from 0 (lowest score) to 5 (highest score) to represent the fitness of using the characteristic to differentiate the learning targets; that is, the perfect score of the eight characteristics was 40. Moreover, there were 11 butterflies (elements) to be differentiated in this learning activity; therefore, 88 rating values needed to be determined in the knowledge grid. If the rating value for describing the observed characteristic of a learning target was correct, the student got 1 point; that is, the perfect score for the second factor was 88. Consequently, the total perfect score of the students' differentiating competence represented in the knowledge grid was 128. This scoring mechanism was validated by an expert who had years of teaching and research experience concerning grid-based knowledge acquisition methods. Moreover, by applying the Pearson correlation analysis, it was found that the knowledge grid scores rated by the two teachers were highly consistent, with a correlation coefficient of 0.81 ($p < .01$), showing the reliability of the scoring mechanism.

4. Results

4.1. Learning achievements

A pre-test was conducted to ensure that both groups of students had the equivalent basic knowledge required for learning the subject unit. Table 2 presents the t-test results of the pre-test. Notably, the mean and standard deviation of the pre-test were 74.9 and 7.15, respectively for the control group, and 78.10 and 9.95 for the experimental group. As $t = -1.18$ and the p-value (Significant level) > 0.05, it can be inferred that in the pre-test, these two groups did not differ significantly; that is, the two groups of students had statistically equivalent abilities in learning the subject unit.

The test items of the post-test aimed to evaluate the knowledge for distinguishing butterflies based on their characteristics, which is the objective of the subject unit. The post-test scores were used as an indicator for representing the learning achievements of the students. Table 3 shows the t-test results of the post-test. The students in the experimental group had significantly better achievements than those in the control group ($t = 3.58$, $p < .001$), implying that the MUKS is helpful to students in improving their learning achievements in terms of discriminating and distinguishing butterflies.

Table 2
t-test of the pre-test results.

	N	Mean	S.D.	t
Control group	20	74.90	7.15	−1.18
Experimental group	21	78.10	9.95	

Table 3
t-test of the post-test results.

	N	Mean	S.D.	t
Control group	20	58.70	14.10	-3.58^{***}
Experimental group	21	72.76	10.95	

$^{***}p < .001$.

Table 4
Paired-samples *t*-test of the scores of the knowledge grids developed in the first and third phases.

	Mean	N	S.D.	*t*
Scores of knowledge grids developed in the first phase	28.50	21	14.73	−9.81***
Scores of knowledge grids developed in the third phase	76.62	21	28.14	
First factor				
Scores of characteristics in the first phase	6.52	21	8.25	−7.13***
Scores of characteristics in the third phase	43.36	21	21.75	
Second factor				
Scores of descriptions in the first phase	28.50	21	14.73	−9.23***
Scores of descriptions in the third phase	76.62	21	28.14	

***$p < .001$.

4.2. Field differentiating competence

This study further investigated the students' field differentiating performance by evaluating the knowledge grids developed during the learning process. In this study, the learning activity for the students in the experimental group consisted of three phases. In the first phase, the students were guided to observe the learning objects in the butterfly garden and to develop their own knowledge grids. In the second phase, the students were asked to share their knowledge grids with others. In the third phase, the students were asked to observe the learning objects in the butterfly garden again, and to modify their knowledge grids according to their observations.

The paired-sample *t*-test results for the scores of the knowledge grids developed by the students in the first and third phases are shown in Table 4. The mean scores of the students' knowledge grids developed in the first and the third phases were 28.50 and 76.62 with $t = -9.81$ and $p < .001$, revealing statistically significant improvements in field differentiating competence after participating in the u-learning activity.

Furthermore, the scores of the characteristics for differentiating the butterflies (the first factor) and the descriptions of the butterflies (the second factor) given by the students in the two phases were compared. It was found that the students had significantly better competence in determining both the first factor ($t = -7.13$, $p < .001$) and the second factor ($t = -9.23$, $p < .001$) after participating in the learning and knowledge sharing activity with the knowledge grid approach.

In conclusion, the students using the grid-based knowledge acquisition approach outperformed their peers using the conventional u-learning approach on both the identification and learning tasks. This finding conforms to what has been pointed out by Jonassen (2000) that Mindtools can engage students in higher order thinking. It also conforms to what researchers have indicated that representing knowledge in grids not only makes it easy to inspect and analyze knowledge, but also amplifies individuals' ability to recognize the distinctions between the targets (Chu, Hwang, & Tsai, 2010; Cragun & Steudel, 1987; Ford et al., 1991). That is, MUKS is able to engage students in distinguishing learning targets in an easy-to-use manner owing to the adoption of the grid-based knowledge acquisition approach.

5. Conclusions and discussion

In this study, a knowledge engineering approach is proposed for developing a Mindtool, MUKS, to assist students in interpreting, organizing and sharing knowledge in a context-aware u-learning environment. A learning activity was conducted on an elementary school natural science course to show the effectiveness of the new approach in helping the students toward higher order thinking. During the learning process, MUKS guided the students to observe the target objects in the real-world learning environment and to develop their own knowledge grids; that is, the students needed to organize their knowledge via "experiential thinking". In the second phase, the students were guided to share their knowledge grids with others and revise the knowledge grids after making further observations; that is, they were asked to do reflective thinking.

The experiment results show that this innovative approach is helpful to the students in improving their knowledge structure as well as their learning achievements in comparison with the "pure" u-learning approach that guides and provides hints to the students to observe target objects in the real world without the aid of the Mindtool. This finding complies with what has been reported by other researchers, that is, students will improve significantly when they participate in learning socially, and interact in the learning activities to share their knowledge (Häkkinena & Järveläb, 2006; Reychav & Te'eni, 2009; Chu, Hwang, Tsai, & Chen, 2009), particularly, when using hand-held devices (Hwang & Chang, 2011; Nussbaum et al., 2009). The effectiveness of the proposed approach can also be explained by what has been pointed out by Norman (1993) that the thinking aspects can be distinguished into two forms; that is, "experiential thinking" and "reflective thinking". Experiential thinking means making decisions or learning according to one's own experiences; reflective thinking, on the other hand, requires deliberation. Norman contended that reflective thinking occurs when students construct new knowledge by adding new representations, modifying old ones, and comparing the two.

Although MUKS seems to be effective and promising, there are some limitations to the current approach. As the grid-based method is suitable for representing classification knowledge, such as the identification of plants, animals or diseases, it can be applied to courses that are relevant to the classification of knowledge, such as medical treatment, natural science or chemistry (Chu, Hwang & Tsai, 2010). To develop effective Mindtools for other courses that are not related to the classification of knowledge, such as mathematics or experiment procedures, one might need to find more suitable approaches.

Furthermore, although MUKS is helpful to the students, the teaching burden for the teachers in scoring the knowledge grids can not be neglected; therefore, in the future, it is important to provide a system to assist the teachers to evaluate the knowledge grids with an easy-to-follow procedure. In addition, it should be noted that the proposed approach is not suitable for the whole curricula. For those subject units that do not focus on differentiating knowledge, MUKS may not be a good choice. Consequently, there are several other issues to be investigated in the future:

(1) In the present study, the use of sensing technology (e.g., RFID) to locate and record contextual aspects of the learning experience has not yet been fully investigated; therefore, one of our future studies is to analyze the students' real-world learning behaviors recorded by the sensing devices to explore the learning patterns of the students in depth.
(2) In the experimental design of this study, the treatment could benefit the experimental group excessively so that the learners might not in fact contribute the constructs themselves. Therefore, it is worth conducting an expanded study to investigate the effects of this approach by in-depth analyses of future students' learning outcomes.
(3) For those subject units that focus on fostering students with different types of knowledge or competences, it is worth developing new learning guidance mechanisms or Mindtools to help students in improving their learning effectiveness.

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