British Journal of Educational Technology Vol 42 No 5 2011 778–789
doi:10.1111/j.1467-8535.2010.01102.x

A concept map approach to developing collaborative Mindtools for context-aware ubiquitous learning

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Abstract

Recent advances in mobile and wireless communication technologies have enabled various new learning approaches which situate students in environments that combine real-world and digital-world learning resources; moreover, students are allowed to share knowledge or experiences with others during the learning process. Although such an approach seems to be promising and innovative, researchers have indicated several problems when applying it to practical applications, in particular, the lack of proper strategies or tools to assist the students to learn collaboratively in such a learning scenario with abundant content. Students might feel interested when using the mobile devices to learn; however, without proper assistance or guidance, their learning achievements are usually disappointing. To cope with this problem, this study proposes a concept map-oriented Mindtool for collaborative ubiquitous learning. Experimental results from a natural science course in an elementary school show that this approach not only enhances learning motivation but also improves the learning achievements of the students.

Introduction

Owing to the advance and popularity of computer and network technologies, computer technology-enhanced learning has attracted the attention of researchers in recent years (Ge & Land, 2004; Liaw, Huang & Chen, 2007; Williams van Rooij, 2009). Although several studies have demonstrated the benefits of learning with computers (eg, Pena-Shaffa & Nichollsb, 2004; Tsai & Tsai, 2003), educators have emphasised the importance and necessity of 'authentic activities' in which students can work with problems from the real world (Brown, Collins & Duguid, 1989; Chu, Hwang & Tsai, 2010; Minami, Morikawa & Aoyama, 2004; Wenger, 1997). That is, it is important to place students in a series of designed lessons that combine both real and virtual learning environments (Hwang, Tsai & Yang, 2008).

Recent advances in wireless communication and mobile technologies have provided an opportunity to accomplish this objective. With the help of these new technologies, individual students are able to learn in real situations with support from the computer system and to share knowledge or experiences with others by using a mobile device with the wireless communication facility. Moreover, via the sensing technology, the learning system is able to detect and record the learning behaviours of the students in both the real world and the digital world. Such a new technology-

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enhanced learning approach has been 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 interact with the learners more interactively (Chu, Hwang & Tsai, 2010; Hwang, Kuo, Yin & Chuang, 2010; Hwang, Tsai & Yang, 2008; Ogata & Yano, 2004; Yang, Okamoto & Tseng, 2008).

On the other hand, Vygotsky (1978) indicated that knowledge can be constructed through social interactions among peers. Interactions with peers face to face in the real world enable students to reflect upon different past experiences and thoughts. Vygotsky further emphasised that cognition originates from social activities, so learning is not only learners' reception and adaptation of new knowledge but a process of merging into a knowledge community (Jonassen, Davidson, Collins, Campbell & Haag, 1995; Vrasidas, 2000; Vygotsky, 1978). Norman (1993) further indicated that thinking can be divided into two categories; that is, experiential thinking and reflective thinking. Experiential thinking refers to a learning process of decisions or personal experiences, while reflective thinking shows deeper reflection that happens when students add novel descriptions, revise old ones and compare the two to construct their knowledge. According to Burleson (2005), awareness and reflection can help develop students' meta-cognition to enhance their learning and creativity abilities. Therefore, it is important to enable students to construct knowledge and to experience reflective thinking through interaction with peers.

Although mobile and ubiquitous learning seems to be a promising learning approach to support situated learning with peer communications, without proper support, these new learning scenarios might be too complex for the students, and the learning achievements could be disappointing. Educators have indicated that 'technologies should not support learning by attempting to instruct the learners, but rather should be used as knowledge construction tools that students learn *with*, not *from*' (Jonassen, Carr & Yueh, 1998, p. 1). Among the existing technologies, computers have been recognised to be the most effective tool for supporting learning and instruction, such that the learners function as designers, and the computers function as Mindtools for interpreting and organising their personal knowledge (Jonassen, 1999; Jonassen *et al*, 1998; Kommers, Jonassen & Mayes, 1992). Therefore, it has become an important and challenging issue to develop collaborative Mindtools to assist learners to interpret and organise their personal knowledge in a context-aware u-learning environment.

To cope with this problem, this study presents a collaborative Mindtool for mobile and ubiquitous learning based on the concept map approach. Moreover, a learning activity has been conducted to evaluate the effectiveness of the innovative approach. Experimental results show that the learning achievements of the students who learn with the collaborative Mindtool achieve significantly better results than those who participate in tour-based mobile learning or the traditional concept map approach.

Literature review

Despite the fact that computer technology-enhanced learning has been widely discussed and employed in past decades, educators have emphasised the necessity and importance of 'authentic activities' in which students can work with problems from the real world (Herrington & Oliver, 2000; Hwang, Tsai & Yang, 2008; Lave, 1991). Researchers have also indicated several critical tasks involved in instructional design for situated learning (Chu, Hwang & Tsai, 2010; Hwang, Tsai & Yang; 2008; Young, 1993) such as the provision of the necessary 'scaffolding' for novices to operate within the complex real-world context (Bruner, 1986; Hwang, Yang, Tsai, & Yang, 2009; Vygotsky, 1978; Williams van Rooij, 2009), the provision of supports to enable teachers to interact knowledgeably and collaboratively with individual students or cooperating groups of students, and the provision of facilities for preparing situated learning activities to assist the

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students in improving their ability to utilise skills or knowledge (Collins, 1991; Ogata & Yano, 2004; Leng, Dolmans, Jöbsis, Muijtjens & Vleuten, 2009; Nussbaum *et al*, 2009).

The advance and popularity of mobile, wireless communication and sensing technologies have attracted much attention from researchers who engage in the study of computer technology-enhanced situated learning. In such a context-aware mobile or ubiquitous learning environment, learners usually hold a mobile device to interact with real-world objects with support from the learning system via wireless networks and sensing technology. Several studies have been conducted to demonstrate the usage of these new technologies in supporting authentic learning. For example, Chu, Hwang, Huang and Wu (2008) demonstrated a technology-enhanced environment in which the learning system guided the students to learn in the real world using sensing technology to detect the learning behaviours of individual students. Hwang *et al* (2009) developed a context-aware u-learning system for training students in the use of the 'single-crystal X-ray diffraction procedure' in a chemistry course. Furthermore, Chen, Hwang, Yang, Chen and Huang (2009) developed a ubiquitous performance support system to assist teachers in class management and student consultation. 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.

Among various approaches for providing the necessary 'scaffolding' for students to learn within a complex context, Mindtools have been recognised as an effective way of assisting students in interpreting and organising their personal knowledge. A Mindtool is a computer-based tool or learning environment which serves as an extension of the mind. Jonassen (1999, p. 9) 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 demonstrated the use of several computer Mindtools such as databases, spreadsheets, semantic networks (eg, concept maps), computer conferencing, hypermedia construction, microworld environments (Dynamic Modeling Tools, eg, active learning environments which simulate real-world phenomena), expert systems, and information and communication technologies (eg, online discussion groups and search engines) (Chu, Hwang & Tsai, 2010; Jonassen *et al*, 1998; Valcke, Rots, Verbeke & Braak, 2007). Some practical applications have demonstrated the effectiveness of such tools. For example, Chu, Hwang and Tsai found it effective to use knowledge acquisition methodologies as Mindtools to assist students in organising their knowledge and learning experiences. Their study also showed that Mindtools and discourse offer 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 in experiencing deep reflective thinking that is necessary for meaningful learning.

Among the existing Mindtools, concept maps have been recognised as being an effective tool for assisting students to represent knowledge and learning experiences (Chu, Hwang & Huang, 2010; Chiou, 2008; Reader & Hammond, 1994); moreover, several studies have shown the benefits of employing concept maps to evaluate the cognitive degree of a set of relevant concepts for individuals (Hwang, Tseng & Hwang, 2010; Liu, Don & Tsai, 2005; Kao, Lin & Sun, 2008a; Panjaburee *et al*, 2010; Peng, Su, Chou & Tsai, 2009; Ruiz-Primo & Shavelson, 1996). Concept mapping was developed by researchers in Cornell University for representing conceptual knowledge structures (Novak & Gowin, 1984; Novak & Musonda, 1991). Several qualitative and quantitative studies have shown that with the help of concept maps, meaningful learning can be effectively promoted, such that positive effects can act upon students (Horton *et al*, 1993; Trent, Pernell, Mungai & Chimedza, 1998). Furthermore, concept maps can also be a visualised cognitive tool supported by computer systems (Anderson-Inman & Ditson, 1999; Fischer, Bruhn, Grasel & Mandl, 2002). The study of Kao, Lin and Sun (2008b) reveals that students' creativity

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can be promoted, and their self-awareness can be improved through reflective thinking with concept map-oriented learning; in addition, the visualisation of concept maps can conduct 'Beyond Sharing' to integrate peers' concept maps into a more complete map. Hence, this study adopts concept maps as Mindtools, whose characteristic, visualisation, enables the students to compare the differences in their concept maps and to experience reflective thinking.

Collaborative u-learning Mindtool with concept map approach

This study aims to conduct collaborative u-learning activities for butterfly ecology observation using a concept map-oriented Mindtool. To support the learning activities, a context-aware ubiquitous learning environment is established by setting up wireless communication networks in a butterfly ecology garden, in which an RFID (Radio Frequency Identification) tag is installed on each target learning object (ie, the butterfly ecology area); moreover, a Mindtool, the Concept Map-Oriented Mindtool for Collaborative U-Learning (CMMCUL), is provided to assist students to cooperatively develop their concept maps.

While learning in the butterfly garden, each student holds a PDA (Personal Digital Assistant) equipped with an RFID reader and wireless communication facility to interact with the learning system and invoke the Mindtool. With the help of the RFID technology, the learning system is able to detect the location of the students and guide them to find the target objects to be observed during the learning process. When the students have arrived at the location of the target objects, the PDA learning system will show the learning tasks or related learning materials to the students. The students then start to observe the learning objects and complete their concept maps with the CMMCUL.

The concept map editing functions of the CMMCUL are provided by invoking the CmapTools developed by the Institute for Human and Machine Cognition (IHMC) of the Florida University System (Novak & Cañas, 2006). CmapTools is a well-known tool that enables users to construct, navigate and share knowledge models represented as concept maps. It allows users to construct concept maps in personal computers and share them on servers via the Internet (http://cmap.ihmc.us/conceptmap.html).

To facilitate the students in developing and modifying their concept maps at different learning stages (eg, before, during and after observing the butterfly ecology), the CMMCUL provides dual modes (ie, personal computer mode and mobile device mode) for developing the concept maps. This facility enables the students to compare the real-world butterfly ecology with the concepts they have learned from the textbooks and have recorded in their concept maps. If the students need to modify the concept maps while observing the butterfly ecology, they can directly make the modifications on their PDA; alternatively, they can take notes on their PDA and make the modifications after discussing them with their peers. Moreover, they are allowed to share their concept maps with their peers via the wireless networks.

In addition to the provision of concept map tools, the learning system provides several functions for teachers. For example, it provides a learning portfolio management function for recording both the real-world and online learning portfolios of the students, as well as user profile management and teaching material management.

Experiment design

To evaluate the effectiveness of the innovative approach, an experiment was conducted to compare the learning achievements and attitudes of the students who participated in a context-aware u-learning activity with different learning strategies.

Participants

The participants are 70 elementary school students in Tainan County. They are, on average, 10 years old and were divided into three groups; that is, 25 subjects in the experimental group, 21

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subjects in control group A, and 24 subjects in control group B. The learning activity was conducted in a butterfly ecology garden located at an elementary school in Tainan County.

Treatments

Figure 1 shows the experiment design of this study. Before conducting the learning activity, each group of students received basic instruction about butterflies; moreover, a pretest and a questionnaire were conducted to analyse the students' knowledge of and attitudes towards butterfly ecology.

In the first stage of the learning activity, the students in the experimental group received instruction in the use of concept maps; meanwhile, they were asked to create their own concept maps about butterfly ecology based on what they had learned from the textbook with the personal computer mode of the CMMCUL in the computer classroom. In the second stage, they were asked to observe butterfly ecology in the authentic environment and revise the concept maps using the mobile device mode of the CMMCUL.

The students in control group A also received the concept map instruction in the first stage, while they were asked to create their initial concept maps about butterfly ecology using the traditional paper-and-pencil approach. In the second stage, they were asked to observe butterfly ecology in the authentic environment and complete their concept maps using the same approach.

On the other hand, the students in control group B neither received the concept map instruction nor developed concept maps during the learning process. Instead, they were guided to learn in the butterfly ecology garden using the conventional u-learning approach; that is, the u-learning system guided the students to observe the target learning objects by raising some questions, giving hints or feedback, and providing supplementary materials to them via the communication facilities and the mobile devices. For example, a student observes the host plant of butterflies 'Hebomoia glaucippe formosana' and describes its leaf shape as 'lanceolate'. By comparing the

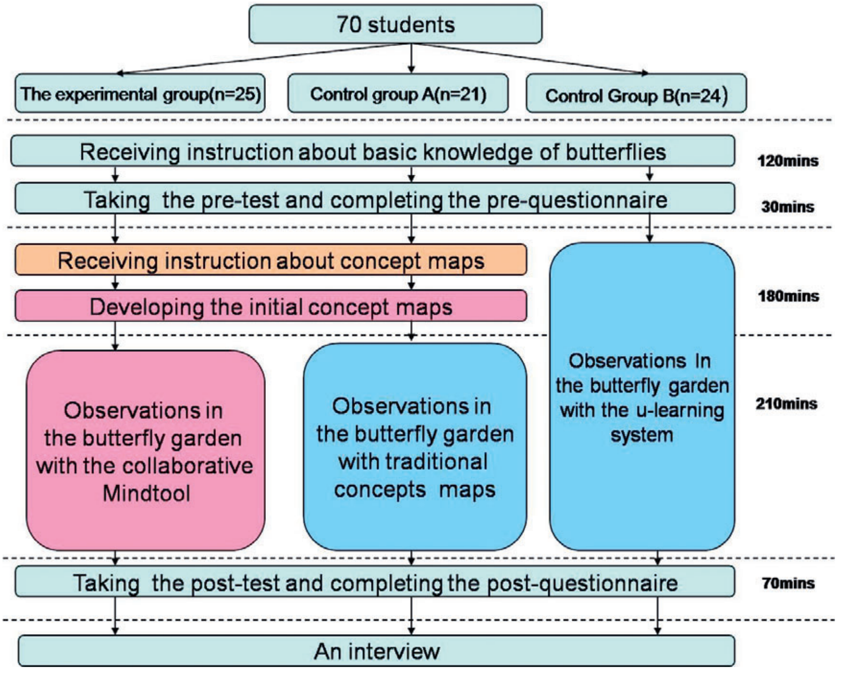

Figure 1: Experiment design

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student's answer with that given by the teacher (ie, 'long elliptic'), the learning system finds that the answer is incorrect; therefore, it will guide the student to observe a nearby host plant 'Zanthoxylum ailanthoides Sieb. & Zucc.' whose leaf shape is 'lanceolate' (ie, the same as the incorrect answer). After the student has observed and compared the leaf shape of the two host plants, the learning system will ask the student to answer the question again. If the student still fails to correctly answer the question, the learning system will show some supplementary materials as well as the correct answer to the student.

While learning in the butterfly ecology garden, all of the students in the three groups were allowed to discuss and share their concept maps with their peers. To better control the factors that might affect the learning, the three groups of students were taught the same learning content by the same teacher. Moreover, to fairly treat the students in different groups, the total learning time of each group was the same; that is, while the students in the experimental group and control group A learned and used the concept map approach, the students in control group B were arranged to learn about butterfly ecology using the mobile learning system.

Test and questionnaire design

A test and a questionnaire were administered both before and after the learning activity to analyse the learning achievements and attitudes of the students. The pretest adopts the 'basic knowledge test of butterflies' designed by Chu, Hwang & Tsai (2010), which has 20 multiple-choice (80%) and 4 matching (20%) items. The posttest, a detailed test about the characteristics of 'Idea leuconoe clara' based on a discussion with experts, contains three parts, namely 10 multiple-choice items (40%), 10 matching items (30%) and 5 short-answer questions (30%).

The questionnaire contains 20 items using a 5-point Likert scale ranging from 1 to 5. It consists of three aspects: seven items about 'attitudes toward science learning', six items about 'self-efficacy of computer skills' and seven items about 'self-efficacy of group learning'. Self-efficacy is an individual's beliefs in his or her capability to successfully perform a task in a particular domain (Bandura, 1996; Zimmerman, 1995). Therefore, individuals with strong self-efficacy will view difficult tasks as challenges that can be dealt with rather than to be avoided. This belief influences an individual's efforts to immerse himself or herself in activities, that is to say, how much effort he or she will expend and how long he or she will sustain efforts when dealing with stressful situations (Bandura, 1993). While there are many factors that influence human behaviour, Bandura identifies self-efficacy as a key mechanism that influences both task performance and cognitive cultivation (Bandura, 1996). In other words, students' sense of self-efficacy affects their interest and motivation in learning activities (Bandura, Barbaranelli, Caprara & Pastorelli, 1996; Pajares, 2003; Zimmerman, 1995). In this questionnaire, the aspect of 'self-efficacy of computer skills' explores the self-efficacy of the students in computer operation, while the aspect of 'self-efficacy of group learning' examines the eagerness of the students to participate in group learning activities, including raising questions or opinions. The Cronbach's alpha value of the questionnaire is 0.887. For the 'attitudes toward science learning', 'self-efficacy of computer skills' and 'self-efficacy of group learning' aspects, the Cronbach's alpha values are 0.796, 0.708, and 0.818, respectively.

Results and analysis

Experimental results and analysis

Before participating in the learning activity, the students completed a pretest to evaluate their basic knowledge about butterfly ecology. A one-way ANOVA was performed on the pretest results, which showed no significant difference ($F = 1.439$, $p > 0.05$) among the pretest results of the students in the three groups.

After conducting the learning activity, an analysis of covariance (ANCOVA) was performed on the posttest results, in which the pretest was the covariance, the posttest results were the dependent

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Table 1: Analysis of ANCOVA of the learning achievement test of the experimental group, and control groups A and B

	n	*Mean*	SD	*Adjusted mean*	F(*2,66*)	p	
Experimental group	25	70.08	9.639	69.755	4.257	0.018	(1) > (2)*
Control group A	21	61.90	8.882	63.396			(1) > (3)*
Control group B	24	65.13	10.010	64.159			

*$p < 0.05$.

Table 2: t test for the questionnaire results before and after learning for the three groups

		Experimental (n = *21*)		*Control A*(n = *15*)		*Control B*(n = *21*)	
		M(SD)	*t*	*M*(SD)	*t*	*M*(SD)	*t*
Attitudes towards science learning	Before	3.97(0.67)	−4.37***	3.86(0.76)	−3.27**	3.99(0.54)	−3.53**
	After	4.38(0.61)		4.40(0.50)		4.54(0.54)	
Self-efficacy of computer skills	Before	3.78(0.71)	−6.20***	4.02(0.71)	−1.48	4.25(0.62)	−1.34
	After	4.45(0.70)		4.36(0.75)		4.50(0.57)	
Self-efficacy of group learning	Before	3.97(0.74)	−2.44*	4.14(0.87)	−1.22	4.14(0.65)	−2.16*
	After	4.29(0.69)		4.30(0.92)		4.56(0.63)	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

variable and the 'different u-learning strategies (three groups)' were the fixed factor, to test the relationships among the posttest results of the three groups. The ANCOVA results are given in Table 1 and show that the learning achievements of the experimental group students were significantly better than those of the students in control groups A and B, whereas no significant difference was revealed between the students in the two control groups. Accordingly, it was found that the CMMCUL was helpful to the students in improving their learning achievements in comparison with the traditional concept map approach and the conventional u-learning approach.

Analysis of questionnaire results

The questionnaire is presented with a 5-point Likert scale where '5' means strong agreement or positive feedback and '1' represents high disagreement or negative feedback. A total of 70 questionnaires were returned. Out of those, 81% were valid (57 out of 70). Table 2 shows the *t*-test of the prequestionnaire and the postquestionnaire results.

For the students in the experimental group, all of the three aspects attained significant improvements. That is, the CMMCUL not only improved the students' attitudes towards science learning but also enhanced their self-efficacy for using computers to learn, and their confidence in and expectations of learning collaboratively with their peers. This finding conforms to several studies that have reported that the use of effective learning strategies and tools not only improves the learning attitudes of students but also encourages their engagement in collaborative learning activities (Chu, Hwang & Tsai, 2010; Nussbaum *et al*, 2009).

On the other hand, for the students in control group A, only the 'attitude toward science learning' aspect improved, while the other two aspects had no significant improvement. Moreover, from the later interview results, it was found that the paper-and-pencil approach significantly decreased the willingness of the students to share their concept maps with peers as well as to revise their concept maps based on their observations. This implies that although the students in control group A learned with concept maps and were allowed to discuss with their peers, their confidence

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in and expectations of using technology to learn and of cooperating with their peers were not improved without the assistance of the computerised concept mapping tool. Such findings conform to the reports of some previous studies (Chiou, 2008; Chu, Hwang & Huang, 2010; Hwang, 2003).

For the students in control group B, their self-efficacy of group learning was significantly improved, implying that the use of mobile and wireless communication technologies in learning enhanced their confidence in and willingness to communicate and collaborate with their peers. However, it was interesting to find, from the later interviews, that the collaboration quality and perspectives of the students in control group B were quite different from those of the students in the experimental group. From the feedback of the students in control group B, it was found that most of them did not use the communication functions provided by the mobile learning system, although they were aware of the functions. That is, without using the concept map approach, the mobile learning system merely played the role of guiding the students to objective locations and presenting the learning materials to them. Under such circumstances, it was difficult and unnecessary for these students to present and share their knowledge via the computer system. This could be the reason why their confidence in and willingness to use computer systems was not significantly enhanced.

Moreover, for the students in the experimental group, it was found that the average ratings of the questionnaire items 'After taking the course, I like to observe the characteristics of butterflies more than before' (4.62), 'Learning with new technology makes me love science courses' (4.48) and 'I like to learn about science through real-object observation' (4.48) were high, revealing that the students were highly interested in taking science courses which use the collaborative Mindtool with the concept map approach.

Interview results

After doing the questionnaire survey, the researchers conducted an interview to collect more detailed feedback from the students. Five students randomly selected from each group were interviewed and asked the following questions:

1. What are the advantages of the learning approach (ie, using the mobile device or the concept map method to learn)? Why?
2. What are the disadvantages of the learning approach (ie, using the mobile device or the concept map method to learn)? Why?
3. Do you think the learning approach (ie, using the mobile device or the concept map method to learn) is helpful to you in collaborative learning? Why?

For the students in the experimental group, 'efficiency', 'structural representation of knowledge' and 'easy to collaborate' were the most significant advantages of the learning approach (ie, using the collaborative Mindtool to learn). For example, all of the five students indicated that the use of the collaborative Mindtool allowed them to represent and maintain the concepts and the relationships between concepts in an efficient way. They also indicated that the innovative approach was helpful to them in sharing their concept maps with peers.

For the students from control group A, 'structural representation of knowledge' was the most significant advantage of the learning approach (ie, using the traditional concept map to learn). For example, three of the students indicated that drawing the concept map was helpful to them in organising their cognition about what they had learned. However, those students also addressed the disadvantages of using the paper-and-pencil approach in revising their concept maps. One of the students said 'It was really difficult to revise the concept map while observing the butterfly ecology. I had to take notes on paper, and then redraw the entire concept map, which was time-consuming'. Another student said 'It took time for me to compare my concept map with

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others. The formats were totally different. When I modified my concept map with pencil, it became disordered and difficult-to-read'. That is, those students felt that the traditional concept map approach was not helpful to them in sharing and maintaining their concept maps.

For the students in control group B, 'interesting' and 'convenient' were the most significant features of the learning approach (ie, using the PDA to learn). While talking about the helpfulness of the approach in collaborative learning, they showed positive feedback but with less confidence. One of the students said 'I think [it is helpful]. The PDA system provided the communication function. But I did not use that function. It is more convenient to talk to my classmates face to face'. Another student said 'When I did not know how to operate the PDA, I asked my classmates'. It seems that the students did not know how to collaborate with others during the learning process because they were guided to learn individually without a clear way to represent or share their knowledge.

Conclusion and suggestions

This study presents a concept map approach to developing Mindtools for supporting collaborative u-learning activities. Based on the innovative approach, a collaborative Mindtool for u-learning, the CMMCUL, has been implemented. The CMMCUL enables students to construct, share and revise concept maps while learning in an authentic learning environment. To evaluate the effectiveness of this new approach, an experiment was conducted which compared the learning achievements of the students who learned with the CMMCUL and those who learned with traditional and conventional u-learning approaches. The experimental results showed that with the help of the collaborative Mindtool, the learning achievement of the students was significantly better than for those who learned with the other approaches.

Moreover, it was found that the students' 'attitudes toward science learning', 'self-efficacy of computer skills' and 'self-efficacy of group learning' were significantly improved after participating in the learning activity. That is, the CMMCUL improved not only the learning achievements of the students but also their attitudes and self-efficacy in learning. In addition to the investigation of self-efficacy towards computer skills and group learning brought about by the convenience of digital editing, this study measured the learning achievements of the students via a pretest and a posttest for evaluating the knowledge levels of the students before and after participating in the learning activity. The experimental results showed that the proposed approach was effective in improving the learning achievements of the students. Such a finding conforms to the situated learning theory that students will be benefited more if they were situated in realistic learning environments (Horz *et al*, 2009). Therefore, this study not only reveals the importance of situating students in real-world learning environments but also shows the effectiveness of using computerised concept maps as Mindtools in such a collaborative learning scenario. The findings in this study can be a good reference for those who intend to study mobile and ubiquitous learning strategies or conduct situated learning activities with Mindtools from both theoretical and practical aspects.

It was also interesting to find that the students who learned with the conventional u-learning approach did not have significant improvement in their learning achievements in comparison with those who learned with the traditional approach. This finding indicates that without effective learning strategies or Mindtools, the performance of mobile or ubiquitous learning could be disappointing. The questionnaire survey and the interview results can be used to explain the reason why the CMMCUL achieved such positive results: first, in comparison with the learning approach for control group A (ie, the traditional concept map method with paper and pencil), the CMMCUL provided a much more efficient collaborative tool for the students to share and modify their concept maps; second, in comparison with the learning approach for control group B (ie, the

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PDA learning system), the CMMCUL provided a much more effective tool for the students to organise and represent their knowledge. Such findings conform to what was reported by Chiou (2008), who indicated that the computerised concept map approach is helpful to students in improving their learning achievements and promoting their learning interest.

Although the CMMCUL seems to be effective, there are some limitations to the current approach. As the user interfaces of most mobile devices are difficult to operate, especially for editing complex graphs, significant modifications to concept maps need to be made in the personal computer mode. Moreover, the small screen size of the mobile devices also limits the display and editing of large concept maps; that is, the teachers need to avoid taking too many concepts into account when designing the learning activities. Consequently, the scale of the u-learning activities with the CMMCUL will be restricted owing to the limitations of the input and output facilities of the mobile devices. In addition, past studies concerning technology-enhanced learning have indicated that these positive results may also be caused by some other factors such as the 'Hawthorne Effect' in which a new technology is liked and more focused on simply because it is new (Fox, Brennan & Chasen, 2008). Therefore, more experiments are required in the future to take these factors into account.

Furthermore, although the CMMCUL is helpful to the students, the teachers' burden when evaluating the concept maps developed by the students could be heavy; therefore, in the future, it is important to provide an automatic or semi-automatic scoring function with an easy-to-follow operating procedure to ease the load of the teachers when evaluating the concept maps.

Acknowledgements

The authors would like to thank the IHMC of the Florida University System for providing CmapTools for use in this study. This study is supported in part by the National Science Council of the Republic of China under contract numbers NSC 98-2511-S-024-007-MY3 and NSC 98-2631-S-024-001.

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