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LONG PAPER

Effects of augmented reality-based multidimensional concept maps on students' learning achievement, motivation and acceptance

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Abstract In this study, an augmented reality-based multidimensional concept map (ARMCM) learning system is proposed for conducting mobile learning activities. The subjects consisted of 65 students with an average age of 11 years in an elementary school in Taiwan. They were divided into an ARMCM group and a multidimensional concept map (MCM) group. An experiment was conducted to evaluate the effectiveness of the proposed approach. The experimental results suggested that students in the ARMCM group performed significantly better than those in the MCM group. Moreover, this study also found that the students using the ARMCM learning approach showed significantly higher motivation than those using the MCM learning approach, because ARMCM learning is able to simulate the complex knowledge that they needed to learn. ARMCM learning was easier to understand and easy to use, as it could simplify the content of the learning knowledge. Pedagogical implications, conclusion, and some suggestions based on this study are provided.

Keywords Augmented reality · Multidimensional concept map · Mobile learning · Interactive learning environments

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1 Introduction

Due to rapid technological progress and the growing popularity of computers in recent years, many teachers are using a variety of learning material, from traditional textbooks and blackboards to a diverse range of multimedia material. Moreover, because of the popularity of mobile devices, students are now experiencing different forms of learning, such as e-learning, distance learning, and mobile learning. In order to deliver such learning content in a more effective manner, numerous cognitive and other tools have been applied with this novel learning material, such as concept maps, expert systems, databases, simulation tools, and visualization tools. Among these, concept maps in particular have been widely used, with many studies showing that these can be used to graphically display or visualize knowledge and thus facilitate comprehensive or organized learning among students [1, 2]. Moreover, studies have also revealed that concept maps can effectively help students and teachers in structuring focal knowledge, and students can thus more easily learn the key content of a course. Alternatively, teachers can use concept maps to design teaching curricula or assessments, as well as to clarify students' misconceptions during learning activities [3–6]. In addition, it has been reported that the use of concept maps in learning activities can help students to improve their learning outcomes in the field of natural sciences [7, 8].

Although concept maps seem to be an effective tool for learning, several problems have been reported. Studies have revealed that when two-dimensional concept maps are used to represent a large or complex knowledge framework, it is then difficult to add more concept nodes to these when needed. Moreover, such concept maps can be complicated and might thus cause cognitive overload among students [5, 9]. In addition, general concept maps

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use boxes and arrows to present a top-down structure that is an expression of the key concepts and their relationships, and this may not be adequate to represent sequential content, such as procedures, timelines, or developments [10].

Huang et al. [9] reported a multidimensional concept map (MCM) approach that can be applied to avoid showing too much information on one screen. Studies have also reported that the MCM approach can be used to demonstrate knowledge content and organize complicated and difficult concept frameworks in an effective manner [5, 11].

With regard to abstract knowledge frameworks and sequential content, appropriate technological tools are required to support the expression of knowledge or learning content [12]. For example, Chen, Chou and Huang [13] proposed an augmented reality (AR) learning system that integrated concept maps as part of the learning content to help students understand abstract knowledge in a natural science context. More specifically, AR can combine virtual 3D objects into a real-world environment to simulate complex concepts and immerse learners in a blended physical environment [14, 15]. Research has shown that the following aspects of science learning are enhanced by AR: spatial abilities, practical skills, conceptual understanding, conceptual change, and collaborative inquiry learning [16].

Studies have also shown that the application of both situated theory and AR as a learning support tool can position learners effectively within authentic classroom practices [14, 16, 17]. Moreover, recent advances in mobile learning have raised the potential for developing AR applications that might help engage students in learning activities through flexible interaction and immersive experiences [18]. The use of AR can thus immerse students in authentic scientific learning [14], stimulate their learning motivation and achievements, and enhance the flexibility and interactivity of learning activities [19].

As such, a novel mobile learning approach that uses the MCM approach with AR technology is thus proposed in this work, and the results demonstrate that it can enhance learning achievement. This study also compares how different MCM approaches affect students' learning motivation and acceptance of the related methods. The specific research questions examined in this study are as follows:

- Does the ARMCM learning approach help students in improving their learning performance?
- Do the students who learn with the ARMCM learning approach have significantly better acceptance of learning materials than those who learn with the MCM learning approach?
- Do the students who learn with the ARMCM learning approach have significantly better learning motivation than those who learn with the MCM learning approach?

2 Literature review

2.1 Concept mapping

Concept mapping was first proposed by Novak in 1984 and was developed based on the meaningful learning theory and cognitive assimilation theory advocated by Ausubel [20]. Researchers have reported that concept maps can help students understand the process of knowledge construction [21, 22]. Among the great variety of learning tools available, concept maps have been proven to benefit students' learning and performance in many subjects, such as biology, physics, chemistry, and storytelling [3, 6, 22, 23]. During development and applications in various fields, concept maps have exhibited the following advantages: (a) they can be incorporated into a teaching strategy, serving as course design standards for teachers to design appropriate teaching material before class [5, 23]; (b) concept maps enable students to engage in meaningful learning and avoid doing so through simple memorization [24, 25]; (c) concept maps help students to organize and clarify different concepts [26, 27]; (d) such maps can also be used as part of a teaching strategy and as a learning evaluation tool [28, 29].

Due to technological advances, concept mapping has been developing toward greater computerization and interactivity. Several studies have indicated that computerized concept maps can enable students to effectively organize their knowledge. For example, Liu et al. [23] proposed an enhanced concept map learning method for teaching the skill of storytelling. In their application, computer-visualized concept maps combined with story grammar were used to help children develop their storytelling abilities. The results of this research showed that computer-visualized concept maps can improve students' ability to structure knowledge related to storytelling.

Hwang, Wu, and Ke [24] applied a teaching strategy involving concept mapping to natural sciences education. Because mobile and wireless communication technology enables learning to occur anytime, at anyplace, an interactive concept mapping-aided learning system for smart phone applications has been proposed. Their experimental results showed that the use of interactive concept maps along with timely feedback not only improved student learning attitudes, but also enhanced their performance.

Nevertheless, the small sizes of the screens used with mobile devices may present problems with regard to computerized concept mapping, with many ideas being crowded into a relatively small area, thus producing a disorganized concept map that increases the cognitive burdens of learners. Researchers have thus proposed using multidimensional concept maps to overcome the disadvantages of traditional approaches.

2.2 Multidimensional concept mapping (MCM)

Huang et al. [9] modified the Novak approach to concept mapping and proposed a teaching structure based on MCM that retains the advantages of the earlier method, leading to in-depth, broad, or remedial learning, while also making such learning more adaptive and personalized. According to the short-term memory theory proposed by Miller [30], the short-term capacity of a person's working memory is 7 ± 2 objects. Therefore, by expanding 2D concept mapping into multidimensional concept mapping, MCM can be used to classify and regroup the unitary concept nodes of a course, thereby simplifying the complexity of the knowledge shown on a single screen.

MCMs integrate related topics to develop a complete knowledge framework. The learning interface initially consists of relatively simple learning units, which then allow learners to select specific concepts to learn at will. As a result, learners can engage in progressive and stepwise learning that is also self-directed. Furthermore, through the extended learning mechanism of MCMs, learners can adaptively undertake multidimensional learning [31]. Huang et al. [5] proposed an MCM teaching approach for web-based computer course teaching. Their experimental results showed that MCM enabled students to improve their learning performance, making them more capable and confident with problem solving. Moreover, their study also revealed that MCMs helped the students incorporate diverse conceptual content and reduced the signs of learning disabilities.

In addition, researchers have applied computerized MCMs to aid students in learning complex courses. For example, Chiou et al. [11] developed an MCM combined with multimedia animations for use in a university accounting course. The MCM they used was a hierarchical knowledge framework featuring hyperlinks linking complex and related concepts. Their results showed that the computerized MCM helped students to understand complicated accounting concepts and improved their learning achievement and satisfaction.

According to the above literature, MCMs can help students construct and organize knowledge; thus, it is a promising approach for developing mobile learning applications with the appropriate technology.

2.3 Augmented reality in education

AR is a rapidly developing computer simulation technology that combines both real and virtual objects. Azuma [32] stated that "AR is a variation of Virtual Environments (VE), or virtual reality, as it is more commonly called. VE technology completely immerses users in a virtual environment; however, while immersed, users cannot see the real world surrounding them. By contrast, AR enables users to see the real world, upon which virtual objects are superimposed" (p. 2). AR has the following three characteristics: (a) the combination of the real and virtual, (b) real-time interaction, and (c) a 3D space for presenting information. Liarokapis [33] summarized the hardware requirements for AR technology and the AR operation process, briefly described as follows: The AR system selects a marker card from which to receive video images through a webcam; the received images are then transmitted to a computer for interpretation by a program before being transmitted through video splitters to output devices for final display on an output screen.

Many educators and researchers now use AR technology for teaching activities in numerous fields, such as mathematics and geometry, design, natural science, and special education [34–38]. Researchers have suggested that using AR technology in learning activities can improve students' learning performance and enable a unique learning environment [34, 39, 40]. Furthermore, using AR technology in learning activities can enable more flexible and interactive course content, and so promote the learning motivation of students [41–43].

Kaufmann and Schmalstieg [44] employed AR to structure an interactive teaching environment, attempting to replace planar images in textbooks with 3D objects to facilitate the learning of complex geometric concepts. They proposed that, based on the different interaction patterns that can occur between teachers and students, AR learning environments can be categorized as follows:

(a) Augmented classrooms. In one example of such a teaching environment, the teacher and selected students each wore a backpack computer equipped with an AR toolkit, a head-mounted monitor with a built-in camera, and a pair of operating gloves. The teacher and students were free to move around to view and manipulate geometric images, communicating through wireless LAN. However, the equipment required for this type of teaching is often cumbersome and expensive, thus limiting its popularization.
(b) Projection screen classrooms. This type of teaching environment is widely used in semi-immersive teaching practice. In the classroom, a large screen is used to project information for learners to watch. The projected content can be either interactive or static. For example, Kerawalla et al. [36] applied AR technology in science education at an elementary school. In their study, projections in classrooms equipped with screens were used to demonstrate how AR technology can simulate the day–night rotation of the Earth.
(c) Distributed hybrid classrooms. In this type of classroom environment, teachers and students can use PCs or handheld devices to experience AR technology in order to show individual activities. The advantage of

> this type of environment is that the personal, semi-immersive equipment required is relatively inexpensive and enables students to select viewing angles and manipulate objects. At the same time, teachers can choose guidance modes to monitor student learning. Chiang, Yang, and Hwang [34] employed a distributed hybrid classroom approach to examine AR learning. In their study, the students used tablets in an AR learning environment to learn in a natural science course. The students were able to use the equipment to engage in the inquiry learning process according to their own pace. The results showed that they found the AR learning approach improved their motivation.

The current study adopts a distributed hybrid classroom as the focal AR learning environment. In this, the students used mobile devices to explore the learning content within the AR learning environment, and this has the potential to provide a portable, flexible learning approach.

3 Research methods

3.1 System design

The learning content is based on the concept of ecosystem, taught as part of a natural science class in elementary school. The basic idea of an ecosystem involves the concepts of circulation, processes, and evolving step-by-step. Since these concepts are abstract, a clear representation of the learning content is necessary. Before implementing the ARMCM learning system, the core of the course's concept map was shown to teachers with experience in teaching natural science classes, in order to gain their opinions on how to improve it. The system was then developed based on the course's concept map, and animations were used to illustrate the abstract concepts.

The ARMCM learning system consisted of three units, the AR environment unit, multidimensional concept map unit, and display unit, as explained in more detail below.

AR environment unit This unit has two layers, (a) a static image layer that is created based on the concepts in the learning content, and which supplies texts and pictures, and (b) a dynamic animation layer that is augmented based on the relationships among the concepts. Vuforia, Unity and 3ds Max softwares were used to implement the learning system. The 3D models and animations were created using 3ds Max software [45]. Vuforia provided the advanced recognition and tracking functions. Its natural feature tracking (NFT) not only helps developers quickly build a stable and accurate AR learning environment, but also lets them design a meaningful pattern database [46]. Finally, Unity was used to implement the ARMCM learning system, so the platform would provide various functions that would enable comprehensive, flexible interactions to occur [47].

Multidimensional concept map unit (MCM unit) This was designed according to Miller's theory [30], which states that human short-term memory is limited to 7 ± 2 items, and the MCM design style proposed by Huang et al. [5]. The complex concepts were thus classified into several sub-concept maps, where each sub-concept map was sized to fit the screen of a mobile device. The use of several sub-concept maps can facilitate learners' comprehension and organization of the related concepts. Using this system, the students can learn step-by-step according to their own pace.

Display unit The teacher uses the PC and pattern cards to present the learning material through the projector. After the teacher's instruction, the students use their mobile devices to manipulate the ARMCM learning system, and they can also use the pattern cards to interact with it. The system then displays immediate feedback according to the students' actions.

The system structure is shown in Fig. 1. There is a webcam device in the display unit that was used to capture the pattern cards, and the display unit was used to send the captured information to the AR environment unit for further processing. In the AR environment unit, Unity was responsible for recognizing and tracking the pattern cards' positions and for comparing the pattern with the database information from Vuforia. Then Unity would build up the real-world scene with virtual objects on a display device. The rules of the present virtual objects were according to the MCM unit.

The virtual objects explained the learning activities through the ARMCM system, as shown in Fig. 2. The virtual objects were shown on the screen. When the students touched the virtual object, the system would show an introduction related to the object. The MCM unit then assisted the students with gradually developing and broadening their knowledge by following the hyperlinks, which are composed of nodes (characters) to represent concepts and links (arrow lines) that connect the nodes to represent the relationship between two concepts [5]. The virtual characters were gradually presented on the screen to demonstrate how the ARMCM system constructs a deepened page. For example, students could learn information about the characters through a profile (Fig. 2). If there were some relationships between the concepts, the learning system would show a question mark on the screen; then, students could touch the question mark to view the animation and learn the relationship.

Figure 3 illustrates the operation. Students could learn the learning contents from the initial screen and if they wanted to gain more advanced knowledge, they could begin in-depth or broad learning observation by following the ARMCM learning system. In the other words, when students had learned the primary concepts, they could use a button to switch to the further concept maps for in-depth learning.

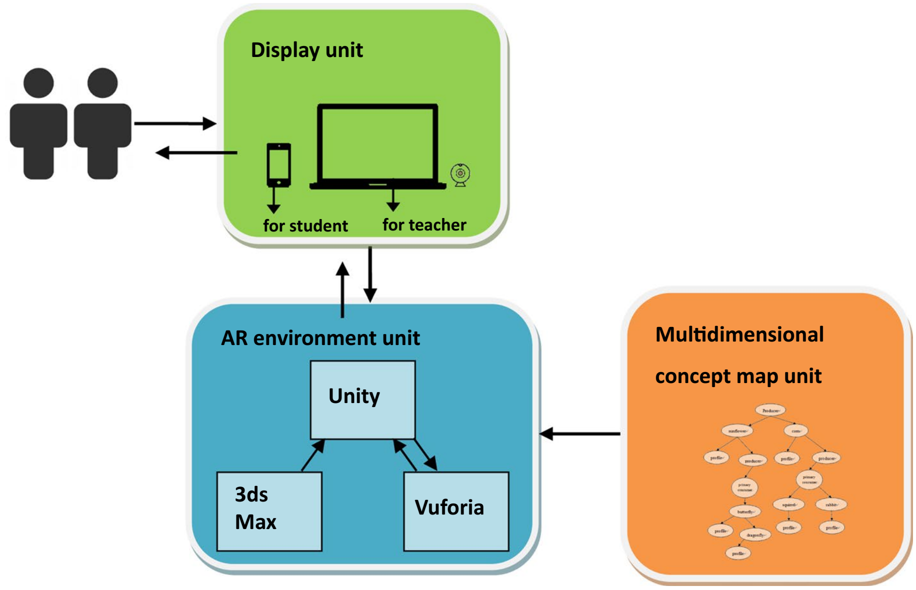


Fig. 1 System structure of ARMCM learning

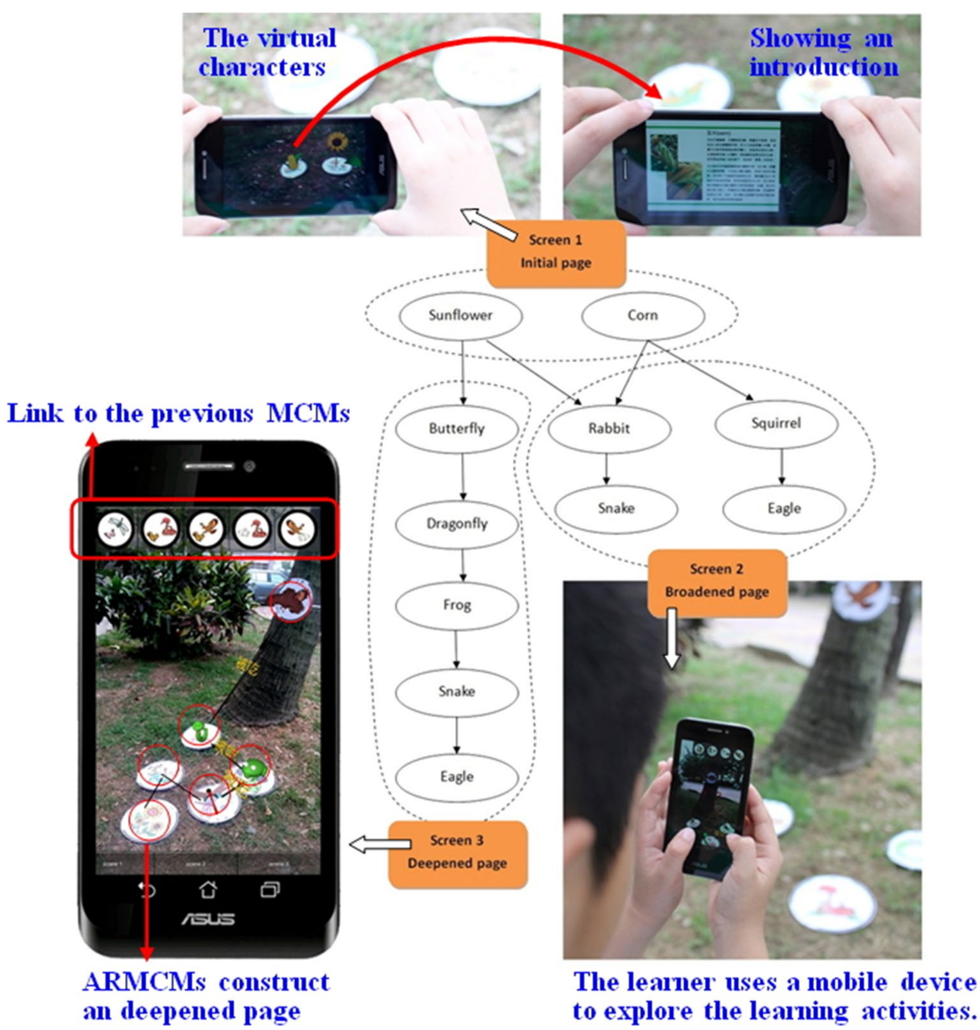


Fig. 2 Illustrating the ARMCM system for learning activities

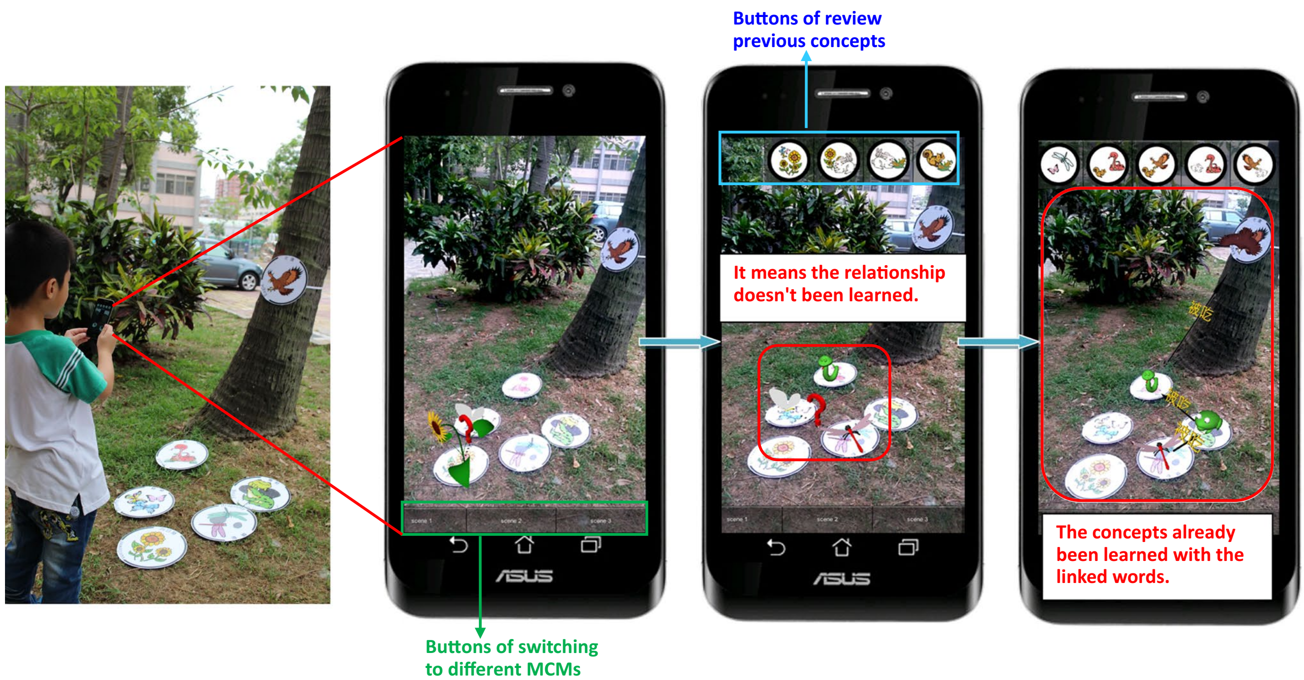


Fig. 3 An example of the ARMCM learning system

While students explored some learning concepts, the learning system would show the linked lines and words between the concepts. In addition, the students could view the virtual objects and animations from any angle by rotating the mobile device.

3.2 Research design and participants

In this study, the ARMCM learning system combines MCMs with AR technology to assist students in organizing their knowledge. The purpose of the study is thus to investigate the effects of this approach on students' learning achievement, motivation, and acceptance of MCMs.

The research structure used in the study is shown in Fig. 4, where the independent variable is the teaching method, and the dependent variables are learning achievement, learning motivation, and acceptance of multidimensional concept maps. In order to obtain accurate results, the variables that could affect the experiment, including learning content, teacher, and learning time, were all controlled.

A nonequivalent quasi-experimental method was employed to explore whether there were significant differences between the MCM group and the ARMCM group. The subjects were 65 students with an average age of 11 years in two fifth grade classes at an elementary school in Taiwan. The two classes were randomly assigned to form the experimental and control groups. The experimental group consisted of 31 students who learned with the ARMCM approach, while the control group was made up of 34 students who learned with the MCM approach. Both groups were taught by the same instructor to reduce external influences on the results.

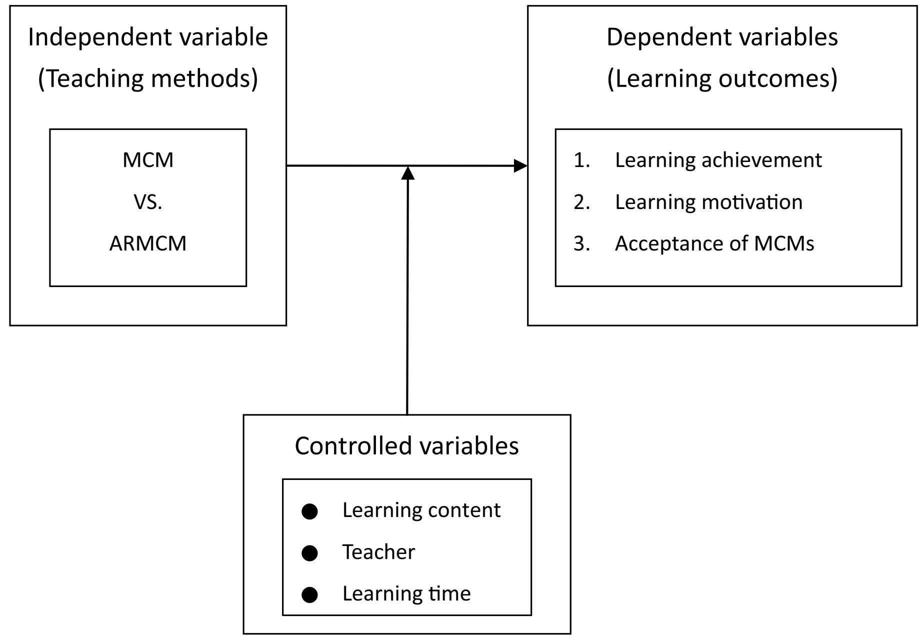
3.3 Experimental material design

The topic of ecosystems was chosen as the teaching material from a natural science course in elementary school. The teaching material for the ARMCM and MCM learning approaches was the same, including the pictures, the animations, and the profiles of the experimental learning course. The teacher used the ARMCM learning approach to instruct the experimental group and the MCM learning approach to teach the control group. In the MCM learning approach, PowerPoint was used to present the teaching content using multidimensional concept maps that structure knowledge with hyperlinks that link nodes of related concepts, such as the profiles of the characters, and the relationship between each character.

3.4 Experimental instruments

The learning achievement tests included a pretest and posttest. The pretest was aimed to ensure the two groups had the equivalent basic prior knowledge, as well as a similar science-related background before the experimental teaching began. The questions in the pretest were chosen from several reference textbooks according to the course's learning objectives. After the teaching experiment, the

Fig. 4 Research structure



posttest was conducted to evaluate the students' learning achievement with regard to the learning content and to make comparisons between the two groups. The maximum score for both the pretest and the posttest was 100 points, and both tests were developed by three teachers who had 5–7 years experience in teaching science courses, in order to ensure expert validity. The Kuder-Richardson reliabilities for the pretest and posttest were 0.76 and 0.80, respectively.

The learning motivation questionnaire consisted of the attention, relevance, confidence, and satisfaction (ARCS) subscales proposed by Keller [48]. It contained a total of 36 questions in a five-point scale, ranging from 1 = strongly disagree to 5 = strongly agree. The Cronbach's alpha values for the four subscales were as follows: attention = 0.86, relevance = 0.787, confidence = 0.807, satisfaction = 0.843. The learning motivation questionnaire was also reviewed by the teaching experts to ensure content validity.

The acceptance of multidimensional concept maps questionnaire originated from the questionnaire developed by Chu et al. [49] and Hwang et al. [2]. It consisted of 23 items that used a five-point Likert scale, with 1 = strongly disagree and 5 = strongly agree (see Appendix 1). This was used to evaluate the students' acceptance of the multidimensional concept maps used in the learning approach, based on their perceptions of usefulness and ease of use. The questionnaire was also reviewed by the teaching experts to ensure content validity. The Cronbach's alpha values for the perception of usefulness and ease of use were 0.869 and 0.877, respectively, indicating a high level of internal consistency for the questionnaire.

3.5 Experimental procedure

The experimental procedure used in this study was as follows. Before the experimental learning activities, the students took a pretest aimed at evaluating whether the MCM and ARMCM groups had equivalent basic prior knowledge of natural science. After the pretest, the teacher taught the ecosystem course to the control and experimental groups using the MCM and the ARMCM approach, respectively.

A posttest was then administrated to the two groups. All of the students completed the learning motivation and the acceptance of multidimensional concept map questionnaires in order to assess their attitudes toward the teaching approaches they were exposed to after the experimental learning was finished.

4 Results

SPSS was used to perform a statistical data analysis based on the results of the pretest, posttest, learning motivation questionnaire, and acceptance of multidimensional concept map questionnaire. The independent samples *t* test was used to determine any significant differences between the results of each test and the questionnaires for the two groups, and the analysis results are discussed below.

4.1 Analysis of learning achievement

The pretest was conducted to confirm that the students in the experimental and control groups had similar capacities and basic knowledge of the course content before the

Table 1 *t* test results of the pretest for the two groups

Variable	Group	*N*	Mean	SD	*t*
Pretest	Experimental	31	90.903	8.912	0.913
	Control	34	88.324	13.229	

experimental learning activity. The pretest results are shown in Table 1. The experimental group scored an average of 90.903, with a standard deviation of 8.912, while the control group scored an average of 88.324, with a standard deviation of 13.229. The results of the independent samples *t* test indicated that $t = 0.913$ ($p > 0.05$), which exceeded a significance level of 0.05. These results demonstrated that the two groups exhibited no significant differences in capabilities and basic knowledge of the course content, meaning that the two groups had equivalent learning backgrounds prior to taking part in the experimental learning activity. Both groups averaged more than 80 on the pretest scores, indicating that both had sufficient knowledge prior to attending the instructional courses in this study.

After participating in the experimental learning activity, the students in both groups took the posttest. Table 2 shows the results of the posttest, where the means and standard deviations for the experimental group were 81.871 and 10.311, and for the control group were 72.118 and 16.200, respectively. The results showed that the experimental group had significantly ($t = 2.864$, $p < 0.01$) better learning achievement than the control group. Moreover, the Cohen's *d* value [50] was used to measure the practical significant difference between the two groups, and this was 0.71, showing a large effect size.

4.2 Analysis of learning motivation

Table 3 shows the results for the students' learning motivation in both groups. The mean values of the experimental and control groups were 4.385 (SD = 0.476) and 4.067 (SD = 0.661), respectively. The result of the independent samples *t* test showed that $t = 2.203$ ($p < 0.05$), indicating significant differences, while the Cohen's *d* value [50] of learning attitude was 0.55, showing a medium effect size. The *t* test result demonstrated that after taking part in the experimental learning activity, the students in the experimental group had more learning motivation for the science course than the control group. Moreover, the results also show that the experimental group had more positive and active learning motivation than the control group.

4.3 Analysis of the acceptance of multidimensional concept maps

Table 4 shows the results for the students' acceptance of multidimensional concept maps during the experimental learning activity. The mean value of the experimental group was 4.467, which was higher than that of the control group, at 4.084. The *t* test result ($t = 3.221$, $p < 0.01$) also showed a significant difference between the two groups, implying that the students in the experimental group had a greater acceptance of the MCMs using in the learning activity than the control group. The Cohen's *d* value [50] of this acceptance was 0.80, showing a large effect size.

Table 2 *t* test results of the posttest of the two groups

Variable	Group	*N*	Mean	SD	*t*	*d*
Posttest	Experimental	31	81.871	10.311	2.864**	0.71
	Control	34	72.118	16.200		

** $p < 0.01$

Table 3 *t* test results for the learning motivation of both groups

Variable	Group	*N*	Mean	SD	*t*	*d*
Motivation	Experimental group	31	4.385	0.476	2.203*	0.55
	Control group	34	4.067	0.661		

* $p < 0.05$

Table 4 *t* test results for the acceptance of MCMs by the two groups

Variable	Group	*N*	Mean	SD	*t*	*d*
Acceptance	Experimental group	31	4.467	0.396	3.221**	0.80
	Control group	34	4.084	0.542		

** $p < 0.01$

With regard to the perceived usefulness of the learning approaches used in this work, the mean value and standard deviation of the experimental group were 4.333 and 0.472, and those of the control group were 4.005 and 0.582 (see Table 5). The t test result for the perceived usefulness was significantly different, with $t = 2.479$ ($p < 0.05$), and thus, the students in the experimental group felt that the learning approach they used was more useful than did those in the control group. With regard to the perceived ease of use, the mean value and standard deviation of the experimental group were 4.642 and 0.416, and those of the control group were 4.188 and 0.628. The t test result ($t = 3.396$, $p < 0.01$) showed a significant difference between the two groups, and thus, the students in the experimental group revealed the learning system was easy to use. The Cohen's d values [50] of the perceived usefulness and ease of use measures were 0.62 and 0.84, respectively, showing large effect sizes.

5 Discussion and conclusion

Concept maps are seen as an effective learning approach, and many past studies have shown that they can be used to improve students' learning achievement [6, 23, 51]. With regard to the teaching of abstract or complex knowledge, there remains a gap in the literature on the effectiveness and usefulness of combining AR technology with multidimensional concept maps in the context of mobile learning activities. This study thus investigated the learning achievement, learning motivation and acceptance of the students with regard to the ARMCM learning approach.

The results showed that the students using the ARMCM learning approach had significantly better learning performance than those using the MCM approach, implying that the former can help students taking a science course. This provides support for a previous study that showed that using the appropriate technological tools to aid in knowledge visualization was able to enhance students' learning outcomes [12]. A similar study by Chiou et al. [11] also noted that MCMs can help students understand the interrelationships among complex concepts. This earlier study also noted that one benefit of MCMs is the ability to combine concepts map with multimedia animations, as this can also improve students' learning achievement. On the other hand, Chiou et al. [52] and Huang et al. [9] showed that computer or mobile screens might not be large enough to support two-dimensional concept maps, especially when they are complicated, as this can lead to cognitive overload among students. Therefore, taking the students' memory load [30] into consideration, the current study designed the MCM learning material in order to reduce the cognitive overload caused by two-dimensional concept maps.

Moreover, the experimental results showed that the students using the ARMCM learning approach had greater learning motivation than those using the MCM approach. As such, it can be concluded that the 3D models and vivid animations that were involved in the former learning activity were able to simulate the complex knowledge that the students needed to learn. The ARMCM approach used AR technology to present the focal material by combining the real-world environment with virtual/digital objects, thus immersing the students in the learning content, which they were then free to explore. Cheng and Tsai [16] indicated that situated cognition is a useful theory for the foundation of AR-based learning in science education. The interviews carried out as part of this study showed that the students were inspired by the ARMCM learning approach and enjoyed the interactions that it enabled. Moreover, it was also able to attract and hold the students' attention, thus raise their learning motivation. The findings of this study echo those of previous works, which also found that integrating new technology into learning activities has the potential to increase motivation [2, 19]. This was also reported in Chiang et al. [34], who examined an AR-based mobile learning inquiry activity. They found that when the students were working with the AR-based system, they were able to learn from the real-world environment and virtual objects in a manner that enhanced their learning motivation.

Furthermore, the students who learned with the ARMCM learning approach had significantly greater acceptance of MCMs. Students preferred the material used with the ARMCM learning because it was easier to understand and use, as the AR multidimensional concept map could simplify the content of the focal knowledge. In the interviews, most of the students in the experimental group stated that the materials used with the ARMCM learning were interesting and well-organized. Several of the students also noted that their interactions with the

Table 5 *t* test results for the subscales of acceptance

Variable	Group	N	Mean	SD	t	d
Usefulness	Experimental group	31	4.333	0.472	2.479*	0.62
	Control group	34	4.005	0.582		
Ease of use	Experimental group	31	4.642	0.416	3.396**	0.84
	Control group	34	4.188	0.628		

* $p < 0.05$; ** $p < 0.01$

ARMCM learning system provided opportunities to practice and deeply explore the course content. Moreover, the students pointed out that the display of the ARMCM's material was easy to understand and that they felt engaged with the animations that were provided. Overall, the students thought that the learning activity with ARMCM was an enjoyable experience and indicated that they would be willing to use this approach in other courses (interview's questions see in Appendix 2).

Summing up the results of experiments and the opinions of the students, three major conclusions can be made. First, ARMCM was an effective and helpful learning approach, and students using it achieved better performance than those using the MCM approach. Second, students using the ARMCM learning approach were more satisfied with and positive about the science course than those using the MCM approach. Finally, the students stated that they preferred the ARMCM material because it was easier to understand and use. In conclusion, the ARMCM learning approach was proposed in this work to help students learn a science course, and the experimental results showed that the students had more positive attitudes toward using this system compared to the MCM approach alone. As such, the ARMCM approach proposed in this study is worth further investigation as a mobile learning method.

Although the ARMCM learning approach assisted in the learning process, there are some limitations that need to be considered in the future. This study only investigated the effectiveness of this approach in a natural science context. The challenge is to integrate AR technology with learning content that will support the demands of teachers and suit the academic abilities of students in different courses. Other limitations of AR learning are that it is time-consuming because it requires developers and teachers to design and develop learning material and activities that are appropriate for students. In addition, this was a small-scale experimental feasibility study for developing an AR learning approach that needs to consider a larger sample of elementary school students. The learning environment is also an important factor for different fields applying AR technology into learning methods.

There are a number of directions worth examining in future work. First, our research team will attempt to apply this approach to other courses, such as mathematics or social sciences, in elementary and junior high schools. We will also explore the potential for using AR technology to design different applications that make use of MCM learning approaches. It could also be a potential scheme to integrate the ARMCM approach with game-based learning or clouding learning, which would make learning more effective and universal.

Appendix 1

Questionnaire of course acceptance with multidimensional concept maps (All questions were originally written in Chinese)

Perceptions of usefulness

1. The learning material for the course is useful
2. The learning material helps me organize the relationships among different concepts in the course
3. The learning material for the course is helpful
4. The learning approach enables me to understand which parts I will have difficulty with
5. The learning material helps me understand the concepts in the course more easily
6. The learning material of the course helps me to focus on the key points in the concepts
7. The learning approach enables me to concentrate on the course material
8. The learning material for the course is useless
9. The learning approach helps me correct some misconceptions
10. The learning approach provides a helpful way for me to understand the differences among the concepts
11. The learning material for this course is hard to understand
12. The learning approach assists me with connecting the course concepts
13. I think the learning approach would be helpful for other courses

Perceptions of ease of use

14. The content of the material is a waste of time
15. The learning material for the course is clear and easy to follow
16. I feel confident in using the learning material for this course to learn
17. The learning material in this course is easy to learn
18. The learning material in this course is hard to use in the learning activity
19. It is easier to find problems when using the material to learn
20. The content of the material is boring
21. This method of learning is more interesting than other alternatives
22. The learning material for this course is easy to use
23. The learning material for this course is exciting to me

Appendix 2

Interview questions

Q1. Do you like this natural science course? Why?

Q2. What was special to you about this course?

Q3. What impressed you the most about this course? Why?

Q4. After using this concept map to learn, do you think this course was easy to learn, or was it the same as usual?

Q5. How do you feel about this learning method?

Q6. Do you want to use this learn method to learn in the future? Why?

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