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REGULAR ARTICLE

# An Augmented-Reality-Based Concept Map to Support Mobile Learning for Science

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**Abstract** Computer hardware and mobile devices have developed rapidly in recent years, and augmented reality (AR) technology has been increasingly applied in mobile learning. Although instructional AR applications have yielded satisfactory results and prompted students' curiosity and interest, a number of problems remain. The crucial topic for AR applications is the lack of appropriate instructional scaffolds to help students organize the content to be learned. Moreover, a lack of appropriate instructional activities and scaffolds often results in student confusion and frustration. Therefore, we integrated AR with concept maps to form a concept-mapped AR (CMAR) scaffold. Subsequently, whether CMAR improves learning outcomes, motivation, and attitude in mobile learning activities was determined. An empirical study was conducted on 71 fifth-grade elementary students in Southern Taiwan. The students were divided into CMAR and AR system groups. The results showed that students in the CMAR group performed significantly better than those in the AR group. The student interview results also showed that the CMAR system helped students organize what they wanted to learn.

**Keywords** Concept map · Augmented reality · Teaching/learning strategies · Elementary education · Interactive learning

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## Introduction

Owing to the popularity of computer equipment and the rapid evolution of information technology, elementary education learning and teaching materials have changed in a variety of ways. Many multimedia and computer-assisted learning systems that provide interactive and effective learning materials have been developed (Benford et al. 2000; Kortbek and Grønbæk 2008; Lee et al. 2011; Madden et al. 2008). Multimedia learning materials have become an essential part of education, and numerous multimedia technologies can be used to develop learning systems such as videos, e-learning websites (Huang et al. 2012), virtual reality (Huang et al. 2010), and augmented reality (Chen and Su 2011; Ha et al. 2012).

Augmented reality (AR) has recently attracted much attention as an interactive technology that enables direct interaction with virtual objects in the real world. New opportunities for AR have been created for education. AR learning applications have been widely used as vehicles for interactive digital learning of the complex and abstract concepts in several curricula, for example, mathematics and geometry (Kaufmann and Schmalstieg 2003), science (Cheng and Tsai 2013), geography (Shelton and Hedley 2002), and art (Serio et al. 2013). Researchers (Billinghurst et al. 2001; Hornecker and Dünser 2009; Lee et al. 2009; Nicolau et al. 2011; Sandor and Klinker 2005) have touted the benefits of AR because it allows students to interact with virtual objects in the real world.

Moreover, AR learning activities have been proposed in many studies which demonstrate that an AR system not only provides students the basics and is flexible and innovative (Pan et al. 2006; Chang et al. 2013), but that it also positively increases the motivation to learn (Serio et al. 2013).

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Although AR has proved to be effective for learning, some researchers (Wu et al. 2013) have stated that an appropriate learning structure and instructional scaffolds are required when using AR. Because current AR systems are often designed from the perspective of developers who do not always consider the needs of teachers, the teachers are not provided definitive learning goals, scaffolds, or structures for their lessons, which substantially reduces student motivation (Kerawalla et al. 2006; Wu et al. 2013) and, in turn, leads to confusion and frustration (Charsky and Ressler 2011).

An appropriate learning structure, therefore, is important for an AR learning system. Many learning structures use mind tools such as concept maps, databases, computer simulation programs, and expert systems (Hwang et al. 2011). The concept map was proposed by Novak and Gowin (1984) as a tool to help students organize knowledge structures. Many researchers have considered the concept maps an effective tool for integrating newly acquired knowledge into prior knowledge and enabling students to establish and comprehend the relationships between concepts (Chiou 2009; Heinze-Fry and Novak 1990; Huang et al. 2012; Hwang et al. 2011).

Therefore, the present study proposed using concept maps as the learning structure for the AR system in an elementary school natural science course. This study compares the efficacy of the concept-mapped augmented reality (CMAR) learning material developed here with that of the AR learning material, which we also developed for this study. An experiment was conducted to investigate the following research questions:

(1) Do students who use the CMAR system learn better (i.e., have better learning outcomes) than those who use an AR system?
(2) Are students who use the CMAR system more highly motivated to learn than those who use an AR system?
(3) Do students who use the CMAR system have a more positive attitude about learning than those who use an AR system?

## Literature Review

AR is a computer graphics technology in which a display of the real environment is augmented by virtual objects (Milgram and Kishino 1994). Azuma (1997) defined the three critical characteristics of an AR system: (a) it combines real and virtual objects in a real-world environment, (b) it provides real-time interaction, and (c) it presents in three-dimensional space. Based on the characteristics of an AR system, many studies report that AR provides near-real-world operation, which enables the user to interact with virtual 3D objects in the real world (Feiner 2002; Shelton and Hedley 2002; Fjeld et al. 2003).

Initial attempts have been made to understand the potential of using AR for education. Billinghurst et al. (2001) used AR technology to design the MagicBook, "a Mixed Reality interface that uses a real book to seamlessly transport users between Reality and Virtuality." The developers designed 3D models using the content of the book and overlaid the virtual model on the real book pages. Kaufmann and Schmalstieg (2003) developed an AR learning system that is a 3D geometric construction tool, specifically designed for mathematics and geometry education, to improve students' understanding of spatial concepts. Hornecker and Dünser (2009) presented an interactive AR system which showed that physical input tools can have a wide variety of interaction behaviors. They found that children expected the digital augmentations to behave and react like physical 3D objects, and were encouraged by the visual feedback and by their ability to interact immediately in three-dimensional space. Clark et al. (2011) implemented an AR system based on natural feature tracking and image processing techniques. That system augmented an educational coloring book and provided a three-dimensional experience using the users' own content, which created an engaging and enjoyable experience for children. Chiang et al. (2014) presented an augmented reality-based inquiry environment in which the learning system guided students to share knowledge in inquiry learning activities. They found that the AR-based inquiry learning activities engaged the students in more interactions for knowledge construction.

Researchers have proposed that because AR systems have highly interactive and tangible user interfaces, they improve the mutual integration of the content to be learned and the virtual object (Dunleavy et al. 2009). Therefore, the content of AR learning presents relevant materials to assist students in immersion learning activities. Several researchers have also stated that AR can improve students' learning attitudes and motivation because of its unique technical features (Pan et al. 2006; Liu et al. 2007; Serio et al. 2013; Ibáñez et al. 2014). Billinghurst (2002) also stated that using AR for instructional materials creates a new type of method that enables students to learn without any previous computer learning experience.

However, Kerawalla et al. (2006) reported a lack of flexible and appropriate instructional content in AR systems, and proposed that (a) the content of AR learning must be flexible so that teachers can adapt it to the needs of students, (b) the students must be able to explore the content by themselves, and (c) the exploration should be carefully scaffolded. Wu et al. (2013) also indicated that appropriate learning structures and scaffolds are required when AR is used. Other researchers (Chu et al. 2010;

Charsky and Ressler 2011) have indicated that the lack of instructional methods and goals when applying this novel technology to learning activities tends to confuse and frustrate students, and even to increase their knowledge overload and decrease their motivation to learn. Therefore, using appropriate learning scaffolds to provide flexible instructional content is a crucial challenge for AR learning. Understanding the limits of immersive media for education is important, particularly because situated learning seems a promising method for learning cognitive skills, such as using inquiry to find and solve problems in complicated situations (Dede 2009).

A concept map is an effective tool that allows knowledge to be structured and integrated in a hierarchical order (Kinchin and Miller 2012; Huang et al. 2012). Martin (1994) stated that using concept maps to prepare instructional materials enables teachers to actively engage in learning activities and identify problems encountered during learning activities, and to subsequently resolve these problems. The concept map is a widely accepted mind tool for promoting learning performance (Malone and Dekkers 1984; Rueda et al. 2009; Wu and Hou 2014). It is reported to enable students to establish accurate concepts through exploration, clarification, and active learning. Concept maps can be used as a type of learning strategy or evaluation tool to identify concepts that are unclear or difficult for students to understand (Cronin et al. 1982; Pendley et al. 1994; Liu et al. 2010; Huang et al. 2012). It can also be used as the standards of course design for assisting teachers in selecting appropriate instructional materials (Markham et al. 1994; Martin 1994; Chen et al. 2008).

Many studies have shown the effectiveness of developing technology-based concept maps to aid in computer-assisted and mobile learning (Charsky and Ressler 2011; Hwang et al. 2013; Liu et al. 2010), but relatively few studies have investigated using concept maps in augmented reality-based learning. Therefore, in this study concept maps were integrated into AR learning to develop an elementary school science course learning system.

## Concept-Mapped Augmented Reality (CMAR) Learning System

### System Structure

In this study, a CMAR system was developed to help students explore and organize what they learned in the course. The topic "food chain" was used as the course content. Food chain is an important subject knowledge in life, and it is also a required course at elementary school in Taiwan. The knowledge about food chain is abstract and complex. Students used the CMAR system which can clearly represent the abstract concepts for students. Three teachers with more than 5 years of science-teaching experience discussed the concept map of the topic for the instructional content of the course. A complete concept map for the course topic was constructed as the core for the CMAR system. During the course, the teacher used the CMAR system to teach the course content, and students used the CMAR system by operating tablet computers to review the basic knowledge and watched the related animations that connected the course concepts. The students also used the system to interact with the maps and cards and to learn their content. The system not only provided immediate feedback, but also enabled students to quickly establish the relationships between the concepts of the course.

Figure 1 shows the system structure of the CMAR system used in this study. CMAR system consists of a CMAR learning module, a concept mapping module, an AR module, a 3D model module, a 3D animation module, and an interaction module. The CMAR learning module is responsible for capturing and representing the details of the screen. When the camera on the tablet PC captures a target, the CMAR learning module decoded the target. And the AR module compared the target to database, and 3D model module and 3D animation module provide the corresponding contents. The interaction module allows students to immediately interact with the system and the cards, and provides the specific feedback to the students. During the learning process, students can complete the concept maps according to their own steps. The concept mapping module facilitates the students organize and comprehend the relationships of the concepts.

Figure 2 illustrates the CMAR system display captured during the CMAR learning activity. On the tablet computers, students were able to view the 3D models and corresponding animations presented in the CMAR instructional materials.

### Operating the CMAR System

Students used the CMAR system to learn the basic knowledge and interrelationships among a set of concepts. Figure 3 illustrates the operation of the learning activities in this study. The materials of the course concepts were divided into three stages based on the various levels of the food chain: primary, secondary, and tertiary consumers. There is both digital and physical content in the learning system to present the CMAR learning materials, including physical maps, cards, digital 3D models, virtual blue lines and red question marks, solid black arrows and linking words, buttons to return to the previous concepts, and buttons to go

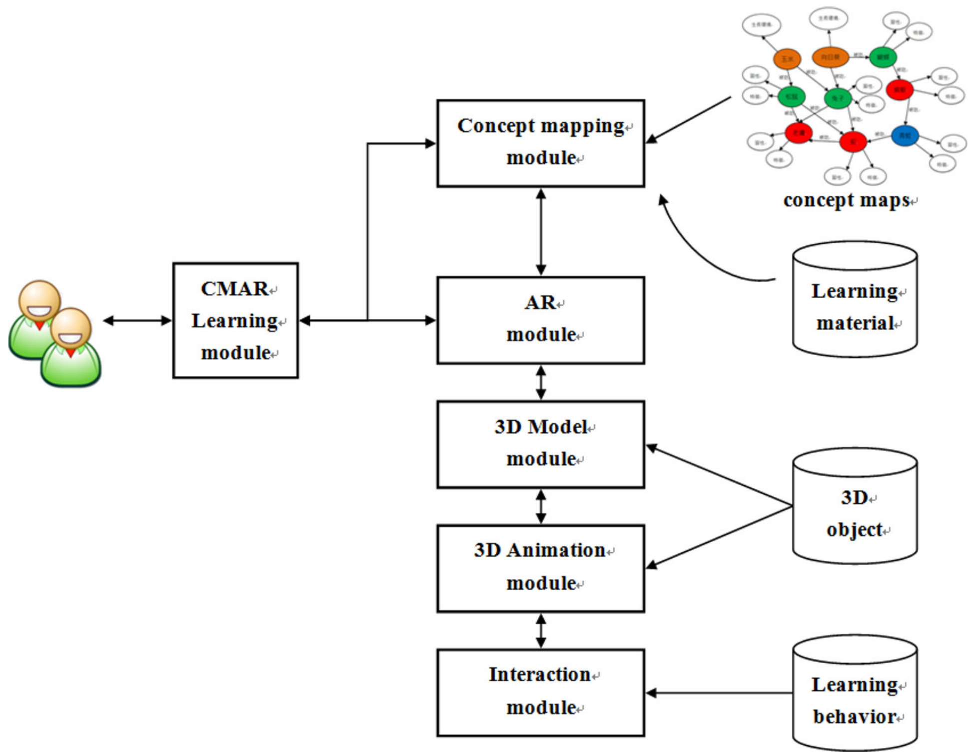


**Fig. 1** CMAR learning system structure

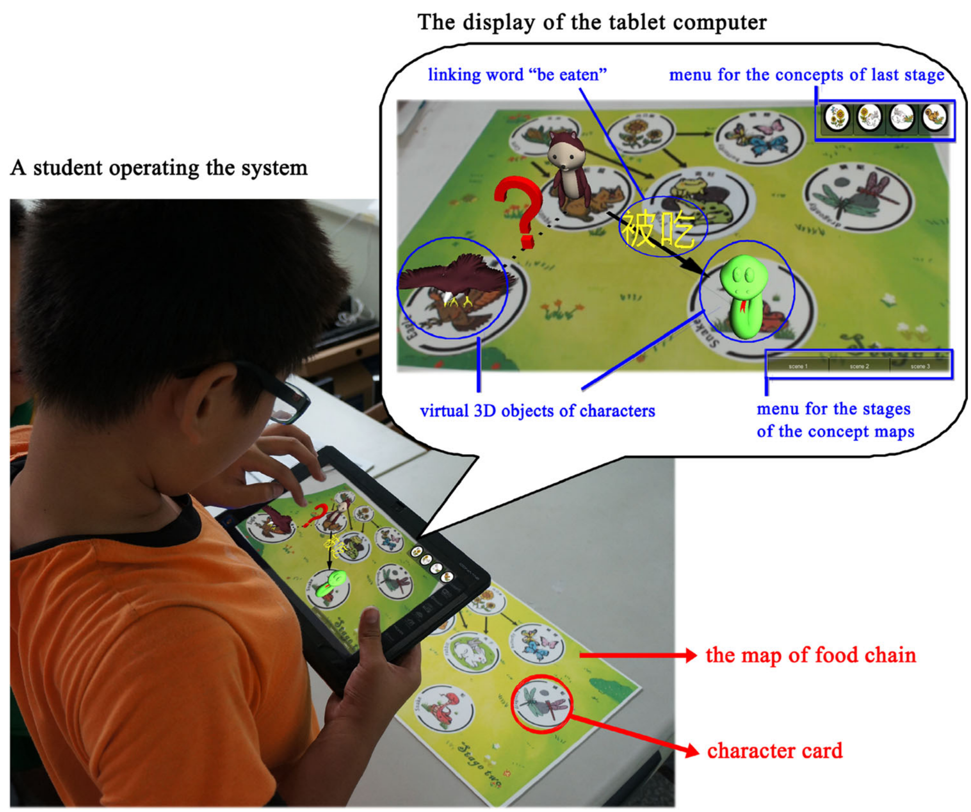


**Fig. 2** Students used the CMAR system during the learning activity

to the different stages. The entire course was presented using the maps of the food chain. Each page of the food chain map represented a stage, and conceptual links from the previous stage were retained in the succeeding one. This enabled students to progressively learn and construct a complete conceptual structure of the course.

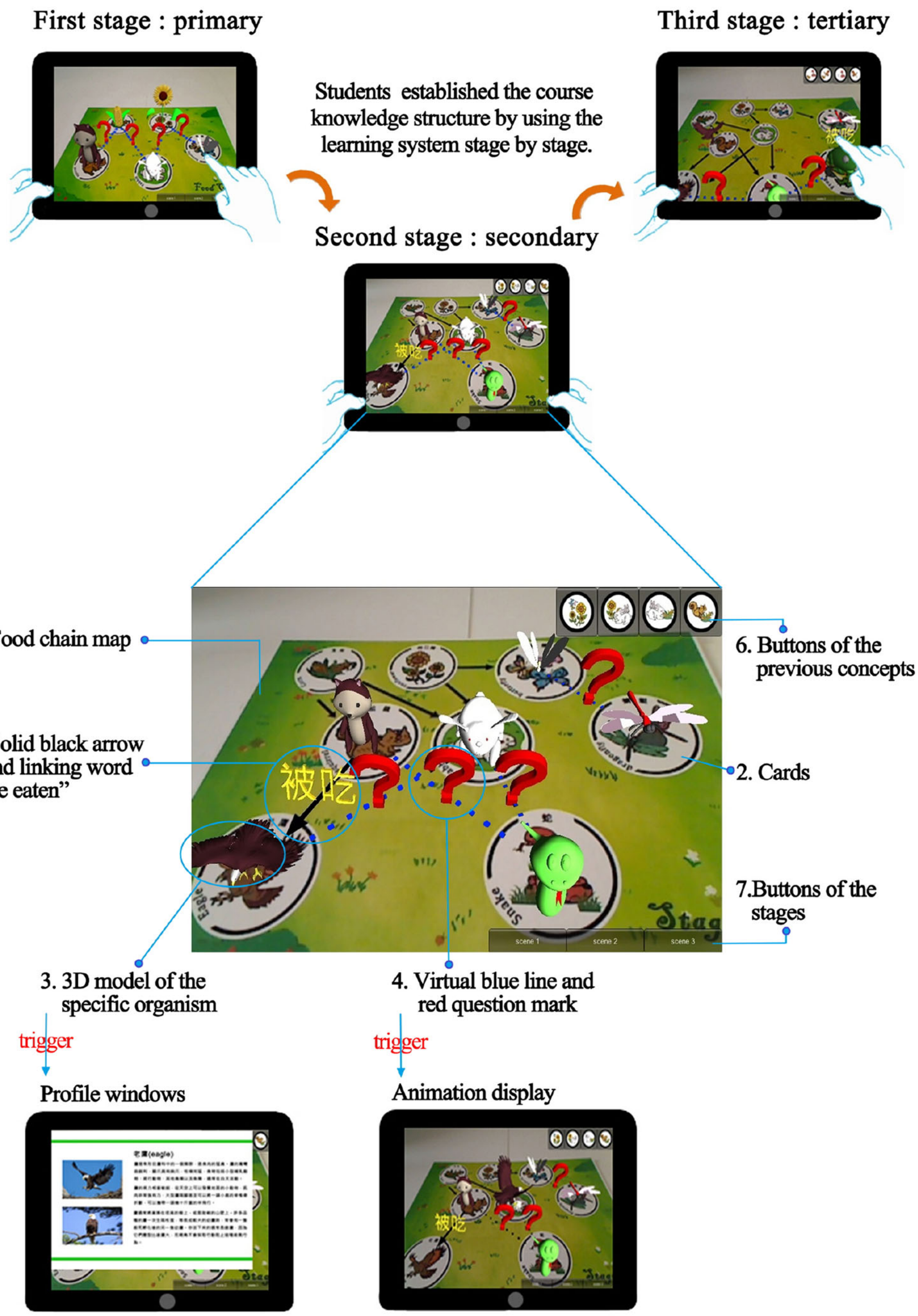


**Fig. 3** Operating the CMAR system

When the tablet computer's camera identified the character cards, corresponding 3D models of these characters were displayed. When the 3D model of a specific organism on the tablet computer was triggered by the students, the corresponding profile of the specific organism would pop up (as shown in Fig. 3). The virtual blue line with a red question mark or a solid black arrow between two organisms represents a connection between them. The virtual blue line indicates that the connection has not yet been learned, while the solid black arrow indicates that the connection has been learned. If the red question mark was triggered, the corresponding animation of the two concepts would be shown on the screen (as shown in Fig. 3). Finally, the buttons in the top right of the window could be used to review the previous concepts, while those in the bottom right could be used to switch to different stages. Students could complete their concept maps according to their preferred order of exploration.

Based on this procedure, students progressively established an entire knowledge structure for the concept of the food chain course. When they had completed the final learning stages, the processes of the complete ecosystem were displayed. Thus, the students organized and established the course knowledge through high-level system interaction.

### Difference Between CMAR and AR Learning Systems

The course content of the CMAR and AR learning systems is the same, and the difference between the two is simply in the presentation of this. The CMAR learning system used the concept map as the learning structure, while the AR learning system used a book, similar to the MagicBook presented by Billinghurst et al. (2001).

The AR learning system in this study was developed with the aid of a printed book. Students used the AR learning system to learn the course content, and could see the 3D models and animations on the physical book by looking "through" the tablet computer, but without the linking line between the concepts. Figure 4 shows the CMAR and the AR learning systems used in this work.

## Methods

### Research Design

In this study, interactive concept maps were used as instructional scaffolds and subsequently integrated in an AR learning system to form the CMAR learning system. To investigate the effect of the AR and CMAR systems on learning outcomes and to determine the variations in learning motivation and attitudes of students in a science course, quasi-experimental methods were used. Specifically, the students were randomly divided into an experimental (CMAR) ($N = 36$) and a control (AR) ($N = 35$) group, and the variable that was tested was the type of learning system used to teach them about nature's food chain.

### Participants

The participants in this study were 71 fifth-grade elementary school students from southern Taiwan. Both groups were taught by the same instructor to eliminate the confounding factors on the experimental results of different personalities, teaching styles, and teaching methods.

### Experimental Material Design

The teaching material was designed based on the course objective: Nature's food chain. Both AR and CMAR instructional methods were designed, and both groups used tablet computers to present the materials. Figure 4a shows the CMAR learning environment with its interactions between the food chain map and character cards. Figure 4b shows the AR learning environment, which presented the content as a book. The organisms were presented in the book as 3D models and animations without concept maps.

### Experimental Instruments

The experimental instruments were the pre-test, the post-test, the learning motivation questionnaire, and the learning attitude questionnaires.

#### *Pre-test*

The pre-test examined relevant prior knowledge before attending the course to determine the homogeneity of the students and to verify that they all had similar science-related backgrounds before the experimental instruction. The pre-test questions were chosen from several reference books according to the course learning objectives, and were also evaluated by the teacher for expert validity. The credibility of the pre-test questions was calculated using the Kuder–Richardson reliability formula, and was found to be 0.79, above the 0.7 threshold that indicates good internal consistency reliability.

#### *Post-test*

After the experiment, the post-test examined the learning achievement of the students in terms of comparison of the

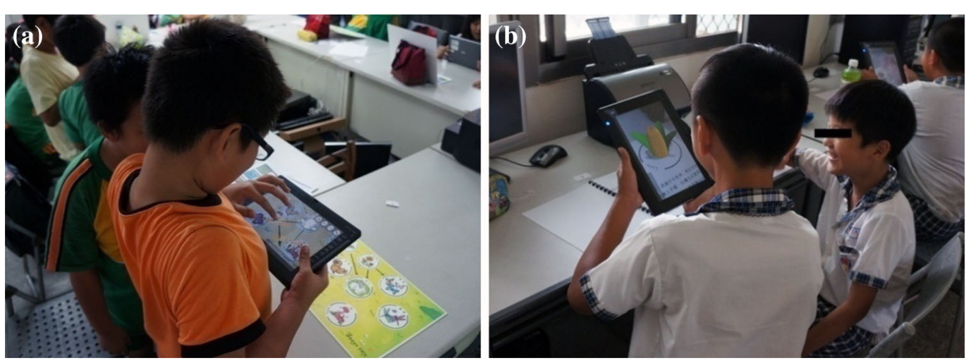


**Fig. 4** Learning environments of the two groups

degree of learning content absorption between the two groups. The post-test, which had a maximum score of 100, was based on the course content and contained six true–false items, six multiple-choice items, and three short-answer questions. The post-test was also evaluated by the teacher for expert validity. The credibility of the post-test questions, as derived using the Kuder–Richardson reliability formula, was calculated as 0.83, well above the threshold of 0.7 and indicating very good internal consistency reliability.

*Learning Motivation Questionnaire*

The Instructional Materials Motivation Survey (IMMS), as developed by Keller (2010) and based on the ARCS motivation model (Keller 1987), was used to assess the impact of the learning approaches on the students' learning motivation. There are many studies on mobile learning or AR-based learning that have also used IMMS to analyze the impacts of these methods on motivation (Chiang et al. 2014; Serio et al. 2013; Wei et al. 2015).

The core components in the IMMS are attention, relevance, confidence, and satisfaction, and the survey includes a total of 36 questions in four subscales, scored using a five-point Likert scale: 1 = *strongly disagree* and 5 = *strongly agree*. The attention subscale measured whether instructional activities attracted and maintained students' concentration; the relevance subscale measured whether connections were established between students and the instructional material; the confidence subscale measured students' confidence in successfully learning the course content; and the satisfaction subscale measured students' learning satisfaction with the experimental course. The questionnaire was reviewed by the experts to ensure content validity. The Cronbach's alpha values for the four subscales of the motivation questionnaire were 0.855, 0.847, 0.822, and 0.823, respectively, indicating a high level of internal consistency for the questionnaire.

*Learning Attitude Questionnaire*

The learning attitude questionnaire originated from the questionnaire developed by Hwang et al. (2013). It consisted of 21 items that used a five-point Likert scale: 1 = *strongly disagree* and 5 = *strongly agree*. It was used to determine students' learning attitude toward science after the experiment. The questionnaire was also reviewed by the experts to ensure content validity. The Cronbach's alpha value of the motivation questionnaire was 0.915, indicating a high level of internal consistency for the questionnaire.

### Experimental Procedures

Figure 5 presents the experimental procedures of this study. Before the experiments, the children were asked to take a pre-test to determine whether they were already familiar with the course content and to complete pre-instruction learning motivation and learning attitude. After the experiments, they were asked to take a post-test and to complete post-instruction learning motivation and learning attitude questionnaires.

### Statistical Analysis

SPSS 17.0 (SPSS Inc., Chicago, IL) was used for all statistical analyses. Independent samples $t$ tests were used to determine significant differences between the two groups in the results of each test and of all questionnaires. Significance was set at $p < 0.05$.

## Results

### Analysis of Pre-test and Pre-questionnaire

Before the experiment, the students in the two groups took the pre-test to confirm that they had equal abilities in this subject before the learning activity. The mean scores and standard deviations of the pre-test were 86.33 and 7.78 for the CMAR group, and 83.83 and 11.73 for the AR group (Table 1). According to the results of an independent samples $t$ test ($t = 1.057$, $p > 0.05$), there were no significant differences between the CMAR and AR groups. That is, the students in the two groups had equal abilities prior to the experiment.

The results of the pre-questionnaire with regard to learning attitude were $M = 3.88$ and SD = 0.81 for the CMAR group, and $M = 3.75$ and SD = 0.62 for the AR group. For learning motivation, the results were $M = 3.93$ and SD = 0.81 for the CMAR group, and $M = 3.95$ and SD = 0.63 for the AR group. The results of the $t$ test showed that the two groups did not differ significantly with regard to either learning attitude ($t = 0.745$, $p = 0.459$) or learning motivation ($t = -0.11$, $p = 0.914$) before the experiment started.

### Analysis of Post-test

Before analyzing the results of the post-test, it is important to consider whether the data can be examined using independent samples $t$ test. This is necessary to validate the normality of the sample distribution and the homogeneity of variance. Therefore, the Shapiro–Wilk test of normal

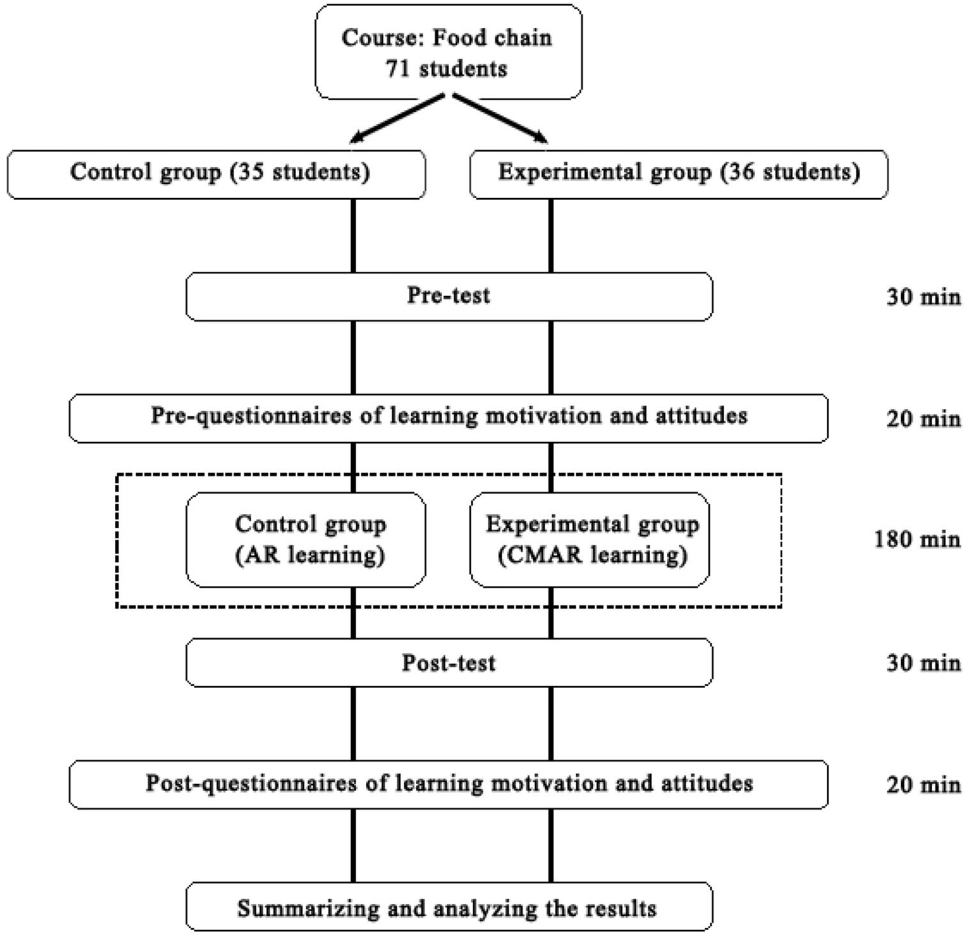


**Fig. 5** Experimental procedures

distribution was used to examine the distribution of the sample (Shapiro and Wilk 1965), while the Levene test was used to test the homogeneity of variance.

The Shapiro–Wilk test showed that the post-test measures were normalized ($W = 0.98$, $p = 0.334$), while the Levene test showed that the variance of the samples was equal ($F = 0.005$, $p = 0.944$). An independent samples $t$ test is thus appropriate for analyzing the results of the post-test.

The post-test scores for the CMAR group were $M = 71.89$ and $SD = 14.56$, and for the AR group were $M = 62.69$ and $SD = 15.23$ (Table 2). The $t$ test results for the post-test showed that the CMAR group had significantly better learning achievement than the AR group ($t = 2.60$, $p < 0.05$). Moreover, the Cohen's effect size was used to measure the practical significant difference between the two groups. Cohen hesitantly defined effect sizes as "small, $d = 0.2$," "medium, $d = 0.5$," and "large, $d = 0.8$" (Cohen 1988). As shown in Table 2, the Cohen's $d$ value of the post-test was 0.62, which suggested a medium effect size of the difference between the two groups.

**Table 1** Descriptive data and $t$ test results of the pre-test and pre-questionnaire

| Variable | Group | *N* | Mean | SD | *t* |
|---|---|---|---|---|---|
| Pre-test | CMAR | 36 | 86.33 | 7.78 | 1.057 |
| | AR | 35 | 83.83 | 11.73 | |
| Learning attitude | CMAR | 36 | 3.88 | 0.81 | 0.745 |
| | AR | 35 | 3.75 | 0.62 | |
| Learning motivation | CMAR | 36 | 3.93 | 0.81 | −0.11 |
| | AR | 35 | 3.95 | 0.63 | |

## Analysis of Learning Motivation

Table 3 shows the descriptive statistics for the learning motivation. The mean scores and standard deviations of the learning motivation were 4.49 and 0.39 for the CMAR

**Table 2** Independent $t$ test analysis and effect size of the post-test results

| Group | *N* | Mean | SD | *t* | *d* |
|---|---|---|---|---|---|
| CMAR | 36 | 71.89 | 14.56 | 2.60* | 0.62 |
| AR | 35 | 62.69 | 15.23 | | |

* $p < 0.05$

**Table 3** Independent $t$ test analysis and effect size of learning motivation

| Group | $N$ | Mean | SD | $t$ | $d$ |
|---|---|---|---|---|---|
| CMAR | 36 | 4.49 | 0.39 | 4.31*** | 1.03 |
| AR | 35 | 3.96 | 0.62 | | |

*** $p < 0.001$

**Table 4** Independent $t$ test analysis and effect size on ARCS subscales of the two groups

| ARCS subscales | Group | $N$ | Mean | SD | $t$ | $d$ |
|---|---|---|---|---|---|---|
| Attention | CMAR | 36 | 4.53 | 0.45 | 4.11*** | 0.98 |
| | AR | 35 | 4.02 | 0.58 | | |
| Relevance | CMAR | 36 | 4.42 | 0.50 | 3.61** | 0.86 |
| | AR | 35 | 3.87 | 0.76 | | |
| Confidence | CMAR | 36 | 4.41 | 0.47 | 4.35*** | 1.03 |
| | AR | 35 | 3.82 | 0.66 | | |
| Satisfaction | CMAR | 36 | 4.63 | 0.42 | 3.23** | 0.76 |
| | AR | 35 | 4.20 | 0.68 | | |

** $p < 0.01$, *** $p < 0.001$

group, and 3.96 and 0.62 for the AR group, respectively. A Shapiro–Wilk test was used to examine the distribution of the sample, and the results supported using the $t$ test. The results of the independent samples $t$ test showed a statistically significant difference between the CMAR group and the AR group ($t = 4.31$, $p < 0.001$). The Cohen's $d$ value of 1.03 indicates a large effect size. The results thus suggest that learning with the CMAR approach raised the students' motivation to a greater extent than learning with the AR approach.

Table 4 shows the descriptive statistics for the four subscales of learning motivation. The highest difference in the mean score among the four subscales was 0.59 for the confidence subscale, while the smallest difference in the mean score was 0.43 for the satisfaction subscale. The samples in the four subscales were normally distributed and the equalities of population variances were equal. The $t$ test results of the four subscales showed that the difference between the two groups was statistically significant with regard to attention ($t = 4.11$, $p < 0.001$), relevance ($t = 3.61$, $p < 0.01$), confidence ($t = 4.35$, $p < 0.001$), and satisfaction ($t = 3.23$, $p < 0.01$). With regard to the confidence subscale in particular, which had the highest difference in the mean score and the most statistically significant results, the findings imply that the CMAR approach helped enhance the students' self-confidence during the learning activity.

The corresponding Cohen's $d$ values of the attention, relevance, confidence, and satisfaction subscales were 0.98, 0.86, 1.03, and 0.76, respectively, showing the large effect sizes (Cohen 1988).

**Table 5** Independent $t$ test analysis and effect size of learning attitude

| Group | $N$ | Mean | SD | $t$ | $d$ |
|---|---|---|---|---|---|
| CMAR | 36 | 4.12 | 0.71 | 2.34* | 0.55 |
| AR | 35 | 3.76 | 0.60 | | |

* $p < 0.05$

### Analysis of Learning Attitude

Furthermore, this study also analyzes the differences in the learning attitudes of the students in the two groups. The mean scores and standard deviations of the learning motivation were 4.12 and 0.71 for the CMAR group, and 3.76 and 0.60 for the AR group, respectively (Table 5). To assess whether there were any significant differences in the students' learning attitudes with regard to the different learning approaches, a $t$ test was conducted. The results showed that the difference between the two groups was significant ($t = 2.34$, $p < 0.05$), while the Cohen's $d$ value of learning attitude was 0.55, showing a medium effect size (Cohen 1988).

### Student Interviews

After the experiment, students provided opinions about their experiences and feedback. Students said that the integration of the CMAR learning provided an interesting and friendly learning method. They enjoyed participating in the science course. The majority of the students mentioned that in addition to the 3D models and animations that attracted their attention, they were able to interact with the connections and character cards presented in the CMAR learning. For example, one of the students said that "I think the connection lines between the characters are a clear and organized way to learn. I can learn about the food chain relationship between the animals. This was an innovative way for me. And I want to learn more about the organisms and hope that the teacher can show more different organisms." These interesting interactive methods deepened the students' impression of the instructional materials. Moreover, some of the students said that they were able to select the specific parts that they preferred to learn more about.

During the study, most of the students, when they were interacting with the character cards, engaged in slapping and grabbing actions. The students explained that these behaviors expressed their intention to interact with the 3D models on the tablet display. For example, one of the students stated that, “I was surprised by how the 3D models were shown on the tablet computer. I can’t see real 3D models on top of the physical cards, so I wanted to grab them just to see what would happen. And I liked the animation between the frog and the dragonfly because it was very lively, and I could see how the frog caught the dragonfly.” These behaviors could occur only when students had become deeply engaged in the environment of the learning system. Additionally, students said that using the CMAR learning method simplified and clarified the instructional materials, and that they were willing to continue using this learning method.

This study obtains the major results from student interviews. First, students preferred CMAR learning that the material was easier to understand and well organized, indicating that the CMAR learning material could simplify the means of displaying knowledge. And from the results of post-test, the CMAR learning was able to promote students’ learning outcome. Second, students enjoyed the food chain course, and they were able to grasp the ideas of the concepts of the course. And students could control their learning progress, which resulted in them having more confidence to pass the course. And from the questionnaire of learning attitude and motivation, students have more positive attitude and motivation toward the CMAR learning.

## Discussion and Conclusion

A concept-mapped knowledge structure was integrated in this study to design a flexible CMAR learning system featuring a learning scaffold. Students were able to engage in learning activities that efficaciously increased their motivation to learn and improved their attitude about learning. We found that students who used the concept map as a knowledge structure in CMAR learning had better learning outcomes than did those who used only the AR learning method. This indicated that using a knowledge structure to support AR learning activities was both crucial and instrumental. This supported the conclusion by Wu et al. (2013) that AR instructional activities require appropriate learning scaffolds.

Moreover, students who used the CMAR system were significantly more positively motivated to learn than were those who used only the AR system. This finding confirmed the conclusions of several studies (Chu et al. 2010; Charsky and Ressler 2011) that adequate learning scaffolds increase students’ motivation when introducing new technology. For example, Liu et al. (2009) used a task-oriented problem-solving method involving AR mobile learning that enabled students to solve problems, complete tasks, and subsequently achieve improved outcomes. Mathews (2010) used a video method that enabled students to use AR-designed content to independently organize and conceptualize their ideas. From the interview, students were inspired by the CMAR system and wanted to learn more about the related organism. They behaved unexpectedly by, for example, “grabbing” and “slapping” at the 3D characters. This showed that they expected that the virtual objects could move just as they do in the physical world. It also showed that the students were interested in the CMAR system.

From the result of the subscale of ARCS, the confidence subscale showed that the CMAR group has more positive attitude toward the course than the AR group. Thus, the results indicated that students who used CMAR were significantly more self-confident about their self-learning. This indicated that the CMAR system enabled students to comprehend definitive learning goals and scaffolds, and to subsequently feel more confident about mastering the course content. Moreover, the attitude questionnaires indicated that students responded positively to the CMAR system. The interview also showed that students believed that the CMAR system helped them organize course content and clarified the presentation of the material to be learned. Therefore, the students wished to continue using the CMAR system. This supported the finding of Hwang et al. (2011) that the concept map-oriented approach not only improved students’ attitudes about learning, but also encouraged them to enthusiastically participate in the instructional activities.

Furthermore, in the interviews, students pointed out that the CMAR system provided interesting and lively displays. They preferred the CMAR to the AR system and were attracted by the animations because their everyday classes at school did not have as many animations to explain the content. The students grabbed the organism cards to look at the 3D models from different angles, and they learned according to their preferred order because the CMAR system provides that apparently desirable flexibility. This finding supported those of studies reporting that an AR system requires highly flexible and appropriate instructional materials with computer-assisted instruction methods (Kerawalla et al. 2006; Cheng and Tsai 2013; Wu et al. 2013).

The advantages of using the CMAR system can be summarized based on our experimental results. First, it provided students with a lively and interesting interactive instructional environment. Second, it simplified and clarified instructional materials and increased students’ learning confidence. Third, using concept maps as knowledge scaffolds provided the AR system with a suitable instructional method. Lastly, it helped students organize and construct course content, increased their learning motivation, and improved their learning attitudes. Therefore, the

CMAR system developed in this study showed that the support of an adequate instructional method and scaffolds when integrating new instructional technology improved learning outcomes.

Although the AR-based learning system helped the students in this study, there are some limitations to this work that should be noted. First, this investigation was only carried out in the context of teaching science, and other fields of study might require different types of CMAR teaching materials and methods. Moreover, the goal of selecting specific course topics that can benefit by combining CM techniques and helpful instructional scaffolds with AR learning requires additional studies and experimentation. Second, tablet computers were used in this study. However, smartphones are becoming larger and more powerful, and thus more people use them for a greater number of online activities. Therefore, prospective CMAR applications should be developed for mobile phone learning methods. Last but not least, the teacher and curriculum are thought to affect the ways in which AR-based learning is carried out, and thus the results that are achieved. Both teachers and developers need to spend more time planning learning activities and designing learning materials to provide learning support. Moreover, the devices needed for AR-based learning remain cost prohibitive for some elementary schools, and this is another challenge to popularizing AR-based learning. Studies related to CMAR systems are scarce. The results of this study can provide a reference and recommendations for subsequent CMAR learning discussions.

## References


Azuma, R. T. (1997). A survey of augmented reality. *Presence, 6*(4), 355–385.

Benford, S., Bederson, B., Åkesson, K. P., Bayon, V., Druin, A., Hansson, P., Hourcade, J., Ingram, R., Neale, H., O'Malley, C., Simsarian, K., Stanton, D., Sundblad, Y., & Taxén, G. (2000). *Designing storytelling technologies to encourage collaboration between young children*. In: Proceedings of CHI 2000, The Hague, The Netherlands, 1–6 April 2000.

Billinghurst, M. (2002). Augmented reality in education. *New Horizons for Learning, 12*.

Billinghurst, M., Kato, H., & Poupyrev, I. (2001). The MagicBook: a transitional AR interface. *Computers and Graphics, 25*(5), 745–753.

Chang, H. Y., Wu, H. K., & Hsu, Y. S. (2013). Integrating a mobile augmented reality activity to contextualize student learning of a socioscientific issue. *British Journal of Educational Technology, 44*(3), E95–E99.

Charsky, D., & Ressler, W. (2011). "Games are made for fun": Lessons on the effects of concept maps in the classroom use of computer games. *Computers and Education, 56*(3), 604–615.

Chen, N. S., Kinshuk, Wei, C. W., & Chen, H. J. (2008). Mining e-learning domain concept map from academic articles. *Computers and Education, 50*(3), 1009–1021.

Chen, C. H., & Su, C. C. C. (2011). Developing an augmented painting interface for enhancing children painting experience. *International Journal of Digital Content Technology and its Applications, 5*(1), 319–327.

Cheng, K. H., & Tsai, C. C. (2013). Affordances of augmented reality in science learning: suggestions for future research. *Journal of Science Education and Technology, 22*(4), 449–462.

Chiang, T. H. C., Yang, S. J. H., & Hwang, G. J. (2014). An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities. *Educational Technology and Society, 17*(4), 352–365.

Chiou, C. C. (2009). Effects of concept mapping strategy on learning performance in business and economics statistics. *Teaching in Higher Education, 14*(1), 55–69.

Chu, H. C., Hwang, G. J., & Tsai, C. C. (2010). A knowledge engineering approach to developing mindtools for context-aware ubiquitous learning. *Computers and Education, 54*(1), 289–297.

Clark, A., Dünser, A., & Grasset, R. (2011, October). An interactive augmented reality coloring book (pp. 259–260). Paper presented at the 10th IEEE international symposium on mixed and augmented reality (ISMAR), Basel.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale: Lawrence Earlbaum Associates.

Cronin, P. J., Dekhers, J., & Dunn, J. G. (1982). A procedure for using and evaluating concept maps. *Research in Science Education, 12*(1), 17–24.

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science, 323*(5910), 66–69.

Di Serio, Á., Ibáñez, M. B., & Kloos, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Computers and Education, 68*, 586–596.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology, 18*(1), 7–22.

Feiner, S. (2002). Augmented reality: A new way of seeing. *Scientific American, 286*(4), 48.

Fjeld, M., Juchli, P., & Voegtli, B. (2003). *Chemistry education: a tangible interaction approach*. INTERACT: Paper presented at the Proc.

Ha, T., Billinghurst, M., & Woo, W. (2012). An interactive 3D movement path manipulation method in an augmented reality environment. *Interacting with Computers, 24*(1), 10–24.

Heinze-Fry, J. A., & Novak, J. D. (1990). Concept mapping brings long-term movement toward meaningful learning. *Science Education, 74*(4), 461–472.

Hornecker, E., & Dünser, A. (2009). Of pages and paddles: Children's expectations and mistaken interactions with physical-digital tools. *Interacting with Computers, 21*(1–2), 95–107.

Huang, H. S., Chiou, C. C., Chiang, H. K., Lai, S. H., Huang, C. Y., & Chou, Y. Y. (2012). Effects of multidimensional concept maps on fourth graders' learning in web-based computer course. *Computers and Education, 58*(3), 863–873.

Huang, H. M., Rauch, U., & Liaw, S. S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers and Education, 55*(3), 1171–1182.

Hwang, G. J., Shi, Y. R., & Chu, H. C. (2011a). A concept map approach to developing collaborative Mindtools for context-aware ubiquitous learning. *British Journal of Educational Technology, 42*(5), 778–789.

Hwang, G. J., Wu, P. H., & Ke, H. R. (2011b). An interactive concept map approach to supporting mobile learning activities for natural science courses. *Computers and Education, 57*(4), 2272–2280.

Hwang, G. J., Wu, C. H., & Kuo, F. R. (2013). Effects of touch technology-based concept mapping on students' learning attitudes and perceptions. *Educational Technology and Society, 16*(3), 274–285.

Ibáñez, M. B., Di Serio, Á., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers and Education, 71*, 1–13.

Kaufmann, H., & Schmalstieg, D. (2003). Mathematics and geometry education with collaborative augmented reality. *Computers and Graphics, 27*(3), 339–345.

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. *Journal of instructional development, 10*(3), 2–10.

Keller, J. M. (2010). *Motivational design for learning and performance*. New York: Springer.

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). "Making it real": Exploring the potential of augmented reality for teaching primary school science. *Virtual Reality, 10*(3–4), 163–174.

Kinchin, I. M., & Miller, N. L. (2012). 'Structural transformation' as a threshold concept in university teaching. *Innovations in Education and teaching International, 49*(2), 207–222.

Kortbek, K. J., & Grønbæk, K. (2008). *Interactive spatial multimedia for communication of art in the physical museum space.* Paper presented at the Proceedings of the 16th ACM international conference on Multimedia.

Lee, H., Billinghurst, M., & Woo, W. (2011). Two-handed tangible interaction techniques for composing augmented blocks. *Virtual Reality, 15*(2–3), 133–146.

Lee, S. H., Choi, J., & Park, J. I. (2009). Interactive e-learning system using pattern recognition and augmented reality. *Consumer Electronics, IEEE Transactions on, 55*(2), 883–890.

Liu, P. L., Chen, C. J., & Chang, Y. J. (2010). Effects of a computer-assisted concept mapping learning strategy on EFL college students' English reading comprehension. *Computers and Education, 54*(2), 436–445.

Liu, T. Y., Tan, T. H., & Chu, Y. L. (2007). *2D barcode and augmented reality supported english learning system.* Paper presented at the Computer and Information Science, 2007. ICIS 2007. 6th IEEE/ACIS International Conference on.

Liu, T. Y., Tan, T. H., & Chu, Y. L. (2009). Outdoor natural science learning with an RFID-supported immersive ubiquitous learning environment. *Educational Technology and Society, 12*(4), 161–175.

Madden, M., Chung, P. W., & Dawson, C. W. (2008). The effect of a computer-based cartooning tool on children's cartoons and written stories. *Computers and Education, 51*(2), 900–925.

Malone, J., & Dekkers, J. (1984). The concept map as an aid to instruction in science and mathematics. *School Science and Mathematics, 84*(3), 220–231.

Markham, K. M., Mintzes, J. J., & Jones, M. G. (1994). The concept map as a research and evaluation tool: Further evidence of validity. *Journal of Research in Science Teaching, 31*(1), 91–101.

Martin, D. J. (1994). Concept mapping as an aid to lesson planning: A longitudinal study. *Journal of Elementary Science Education, 6*(2), 11–30.

Mathews, J. M. (2010). Using a studio-based pedagogy to engage students in the design of mobile-based media. *English Teaching Practice and Critique, 9*(1), 87–102.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems, 77*(12), 1321–1329.

Nicolau, S., Soler, L., Mutter, D., & Marescaux, J. (2011). Augmented reality in laparoscopic surgical oncology. *Surgical Oncology, 20*(3), 189–201.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge: Cambridge University Press.

Pan, Z., Cheok, A. D., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers and Graphics, 30*(1), 20–28.

Pendley, B. D., Bretz, R. L., & Novak, J. D. (1994). Concept maps as a tool to assess learning in chemistry. *Journal of Chemical Education, 71*(1), 9.

Rueda, U., Arruarte, A., Elorriaga, J. A., & Herrán, E. (2009). Learning the attachment theory with the CM-ED concept map editor. *Computers and Education, 52*(2), 460–469.

Sandor, C., & Klinker, G. (2005). A rapid prototyping software infrastructure for user interfaces in ubiquitous augmented reality. *Personal and Ubiquitous Computing, 9*(3), 169–185.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika, 52*(3–4), 591–611.

Shelton, B. E., & Hedley, N. R. (2002). *Using augmented reality for teaching earth-sun relationships to undergraduate geography students*. The First IEEE International Workshop: Paper presented at the Augmented Reality Toolkit.

Wei, X., Weng, D., Liu, Y., & Wang, Y. (2015). Teaching based on augmented reality for a technical creative design course. *Computers and Education, 81*, 221–234.

Wu, S. Y., & Hou, H. T. (2014). Exploring the process of planning and implementation phases in an online project-based discussion activity integrating a collaborative concept-mapping tool. *The Asia-Pacific Education Researcher, 23*(1), 135–141.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers and Education, 62*, 41–49.