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Developing an interactive augmented reality system as a complement to plant education and comparing its effectiveness with video learning

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The learning of plants has garnered considerable attention in recent years, but students often lack the motivation to learn about the process of plant growth. Also, students are not able to apply what they have learned in class in the form of observation, since plant growth takes a long time. In this study, we use augmented reality (AR) technology to develop the ARFlora system, which can assist students in observing the changes in plant growth while in the classroom. More specifically, students are able to use AR markers to manipulate various virtual objects (e.g. sunlight) and observe the changes they have on plant growth. Meanwhile, a quasi-experimental evaluation is in place to substantiate the effectiveness of ARFlora in the learning of plants and to compare it with digital video learning. In the quasi-experimental design, 55 elementary-school students participated in the study. The participants are divided into two groups, an "experimental group" and a "control group." The experimental group was taught using the ARFlora system, while the control group was taught by employing the digital video. Results show that (1) ARFlora and digital video have the same effectiveness on student's learning outcomes; (2) ARFlora is more effective in helping students retain learned knowledge; and (3) ARFlora is comparatively more useful in motivating students to learn about plants.

Keywords: augmented reality; plant education curriculum; constructivist learning; digital video

1. Introduction

Plant education is one of the most important science curriculums (Bebbington, 2005; Huang, Lin, & Cheng, 2010); nevertheless, students often lack motivation toward the study of plants (Silva, Pinho, Lopes, Nogueira, & Silveira, 2011). Studies have shown that students prefer to learn about animals rather than plants (Bebbington, 2005; Schussler & Olzak, 2008; Wandersee & Schussler, 2001), which may be attributable to the fact that humans are animals, thus we tend to overlook the study of plant-related knowledge and only focus on animal-related information (Flannery, 2002; Hoekstra, 2000). As regards plants being neglected, Wandersee and Schussler (2001) introduced the term "plant

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blindness," explaining people are prone to not be aware of plants in their surroundings. This is apparently a problem not just among students, but in the general population. Therefore, an important issue to be addressed is to develop a robust approach to help students learn about plants, thereby minimizing plant blindness.

Many studies have attempted to exploit technology to motivate students to learn in science-related courses. Early on, Internet technology was used to facilitate science learning (Tsai, Lin, & Yuan, 2001, 2002). Tsai et al. (2001) thought with the assistance of the Internet and computers, students should be able to easily engage in the study of science. For example, they can easily develop, modify, and present their concept maps. Consequently, Tsai et al. designed a web-based concept map test system for high-school physics. Their results revealed that, in general, students' views about the use of such systems were positive. Similarly, Tsai et al. (2002) argued that Internet technology can be used to create an environment where students can share their ideas and criticisms that may provide a way of utilizing peer assessment for the purpose of stimulating students to develop science activities. Accordingly, Tsai et al. developed a networked peer assessment system to support inquiry-oriented activities in secondary science education. Their results showed that students who offered detailed and constructive comments reviewing and criticizing other peers' work were able to improve their own work, especially in the beginning stage of revising their original work. Later, mobile technology attracted researcher's attention (Chu, Hwang, Tsai, & Tseng, 2010; Huang et al., 2010). Chu et al. (2010) used radio-frequency identification technology to develop a mobile learning system for detecting and examining real-world learning behavior of students, in which the system is used to provide students with a personalized learning guidance when they observe and recognize the features of plants. Their results showed that the mobile learning system can be used to assist students in promoting their learning achievements and learning motivation. Similarly, Huang et al. (2010) also used mobile technology to develop a mobile plant learning system that provides teachers with method by which to facilitate student learning in an elementary-school-level botany course. Their results indicated that students liked the outdoor learning activities made possible by use of the system and that they also benefitted academically from the use of the system. Recently, researchers have been interested in augmented reality (AR) technology (Hsiao, Chen, & Huang, 2012; Wu, Lee, Chang, & Liang, 2013). Hsiao et al. (2012) proposed an AR learning system to assist students in learning an ecosystems curriculum. In their study, the AR technique was used to support students using their gestures and body movements to interact with the system, in which the gestures and body movements were designed to increase students' levels of physical exercise. Hence, students not only gain knowledge through the curriculum content but also get exercise within the system. Their results showed that an AR learning system can promote students' learning attitudes toward things like learning ecosystems. Similarly, Wu et al. (2013) also argued that AR is suitable for the study of science, because AR techniques can be used to assist students in observing unobservable phenomena (e.g. airflow) or abstract science concepts (e.g. molecular structure).

Among the above-mentioned technologies, AR techniques have special value in the study of plants because they offer a high potential for supporting students to observe the growth of plants. During this learning process, students usually encounter difficulties in observing the growth of plants because the growth of plants is slow, which is an unobservable phenomena. However, the AR technique can be used to superimpose virtual objects onto physical objects that enables the unobservable phenomena and invisible concepts or events to be visualized (Arvanitis et al., 2009; Dunleavy, Dede, & Mitchell, 2009). That is to say, the AR technique can enable students to observe the phenomena that may not be easily examined in the natural environment, such as the life cycles of plants (Wu et al., 2013). In addition, such learning experiences can stimulate students' thinking skills and conceptual understanding of invisible and unobservable phenomena (Liu, Tan, & Chu, 2009) and correct their misconceptions (Sotiriou & Bogner, 2008) because the augmented objects can create visualizations that make the invisible become observable (Wu et al., 2013).

More importantly, AR technology is helpful with the practice of constructivist learning in plant education curriculums. Constructivist learning is derived from the constructivist theory, which argues that knowledge is not just simply transmitted from teacher to students, but rather is constructed in the mind of the students in the form of active learning (Harel & Papert, 1991; Palincsar, 1998). Accordingly, constructionism emphasizes that students should construct personally meaningful and shareable artifacts in order for them to actively explore, examine and extend their knowledge (Girvan, Tangney, & Savage, 2013). During constructivist learning, students can actively engage in learning in which they discuss, argue, and negotiate ideas as well as collaboratively solve problems, while teachers only need to facilitate the learning activities (Palincsar, 1998). Many studies have indicated that with the assistance of AR technology, students can manipulate and interact with real as well as virtual objects to observe the changes in situations or phenomena (Hsiao et al., 2012; Wu et al., 2013). Hence, students can build conceptual models that are both consistent with what they already understand and also with the new content when they use AR technology to practice constructivist learning (Hsiao et al., 2012). In addition, since it takes time for plants to grow, students lack the opportunities to apply what they have learned about plant growth in the classroom, whether in the form of observation or verification. To solve this problem, advanced AR technology can be applied as a useful approach to help students study plant growth, so they are actively involved in the entire learning process.

In this study, we used AR technology to design an eco-learning system, called ARFlora, which is used to help students to experience constructivist learning in a plant education curriculum. Consequently, students can form groups to use the ARFlora to learn about the natural cycle of plant life. Specifically, the system offers an alternative approach to conventional textbook learning, giving students the opportunity to acquire ecological knowledge through an entertaining interactive process. To explore the effectiveness of AR technology on students' learning about plants, a quasi-experimental research design was constructed, in which we implemented the ARFlora and deployed the system at an elementary school. An achievement test and a questionnaire were used to explore both the learning achievement and the learning motivation of students. Finally, a series of analyses were carried out to examine the AR technology and to draw conclusions about the analyses.

2. Related studies on AR technology-assisted learning

A number of studies have attempted to apply technology to motivate students in science-related courses. Among them, AR technology has proven to be useful, as it can effectively integrate virtual information and the real world, and is generally used to provide users with an immersive experience (Azuma, 1997; Dunleavy et al., 2009; Hsiao et al., 2012; Kaufmann & Schmalstieg, 2003). More importantly, AR technology holds the edge in not needing special equipment to enhance the visual effects in a real environment, producing virtual 3D objects that merge together reality and the virtual world. Accordingly, AR technology-assisted learning has received increasing attention in recent years (Wu et al., 2013). Early on, Billinghurst, Kato, and Poupyrev (2001) used AR technology to design a children's book to promote their motivation toward reading. When flipping through the pages, the contents of the book are animated with visual effects and sound right in front of the reader, which adds more enjoyment to learning. Similarly, McKenzie and Darnell (2003) also used AR technology in the design of an interactive book, where users can see movements of characters in the book and listen to vocal instructions thanks to AR markers, ultimately changing people's reading experience in a way that may very well improve reading efficiency. Later, Woods et al. (2004) utilized AR to construct an interactive learning system on the planets in the solar system. By using a set of nine picture cards depicting the planets and placing them correctly on their respective orbits, the system enters orbiting mode, for example, the earth orbits around the sun. With the cards, learners can rotate or closely observe the planets of interest and read facts about the planet's surface or its location in relation to the sun. It was found that the use of AR technology allowed these learners to understand the concept of space and the location of the nine planets. Kirner and Zorzal (2005) designed a spelling game with AR; when the learner spells an English word correctly, the system displays the corresponding object to the word, in turn improving their English vocabulary. Kerawalla, Luckin, Seljeflot, and Woolard (2006) used AR to assist teachers in carrying out activities, targeted at students aged 10–11 learning about the Earth, Sun, and the Moon, where the system-relay-related concepts to students by their manipulation of the 3D content available to them. The results showed AR application to be capable of improving interaction, understanding, and cognitive feedback, as well as learning achievement. Recently, some studies have indicated that AR application in learning can enhance user acceptance. Kye and Kim (2008) investigated the promotion of learning outcomes through the use of AR that explored five factors, that is, perceptual immersion, guidance, operation, display, and smoothness on 260 fifth-grade students. The results showed that perceptual immersion, operation, display, and smoothness affect student satisfaction, understanding, and knowledge, as well as the outcome of applied learning. In particularly, operation was found to be directly related to satisfaction and learning outcomes related to knowledge application. Thus, enhancing an AR touchscreen user interface can improve learning satisfaction and effectiveness. Martín-Gutiérrez, Contero, and Alcañiz (2010) used AR to improve the space perception capability of civic engineering students, enabling students to better grasp the content of construction drawings. The exploration of the effectiveness of AR technology and learning satisfaction in college-level education has shown this system to effectively help students develop spatial capabilities in the production of construction drawings. Overall, the development of AR technology has enabled students to have convenient learning contexts in which to improve their learning outcomes.

Although many studies have investigated AR-assisted learning, there has yet to be any research on the application of AR technology in plant education (Chu et al. 2010; Huang et al., 2010; Silva et al., 2011). In recent years, some studies have attempted to apply other information technologies in plant education, but they are unable to assist students in observing the changes in plant growth (Cheng & Tsai, 2013; Hsiao et al., 2012). AR technology has been established to be effective in assisted learning, and can be used to aid students in the observation of abstract scientific concepts or even phenomena unobservable due to time and space constraints. More importantly, in the AR-assisted learning process, students are given the opportunity to experience constructivist learning, where various virtual information can be tagged in the real world to observe their changes. However, thus far, no studies have dedicated research efforts into the use of AR technology in assisting students to observe plant growth. This present study develops and introduces the ARFlora system to address this unexplored field of research. The system's operational process is described in the next section.

3. ARFlora system for supporting a plant education curriculum

3.1. *System design*

In this work, we aimed to develop an ARFlora system intended to support student engagement in a plant education curriculum. To this end, several AR markers, hardware, and software were used to develop the ARFlora system. Figure 1 shows the framework of the ARFlora system. A webcam, a mechanical clock, and a microphone were used as the input devices for the purpose of supporting students to manipulate virtual objects, in which an Arduino platform (Banzi, 2008) was used to convert the analog signal of the mechanical clock to a digital signal for the manipulation. Specifically, the webcam was used to capture the AR marker information; the mechanical clock and the Arduino platform were used to enable students to operate the changes in time; the microphone was used to enable students to simulate the release of CO_2. In addition, a monitor was used as the output device intended to support student observation of the changes in the virtual objects. Afterward, three software development kits were used to integrate the hardware and further develop the ARFlora system, including the FLARToolKit, Papervision3D, and Serproxy. Specifically, the FLARToolKit is an AR library for the development of the Flash platform; Papervision3D is an open-source 3D engine for the development of the Flash platform; the Serproxy is a middleware that was used to connect with the Arduino platform. Finally, a server with a database was used to store and manage the virtual objects and the animation.

Figure 2 shows the interface of the ARFlora system. Figure 2(a) is the system menu, in which the ARFlora system supports students to learn about three kinds of plants, including creeping woodsorrel, peanut vines, and mimosa. These plants have respective characteristics, so that students can learn the growth process of different plants, from germination, seedling growth to flowering. Figure 2(b) is the user interface that can be divided into three areas. Area (I) is the presentation and interaction window, where students can observe changes in the virtual objects. Area (II) shows AR marker currently in use.

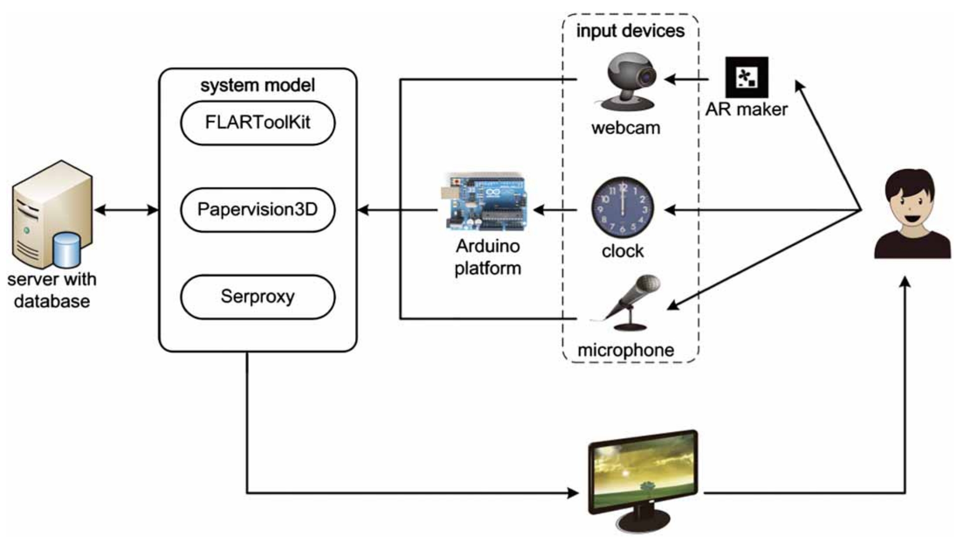

Figure 1. The framework of the ARFlora system.

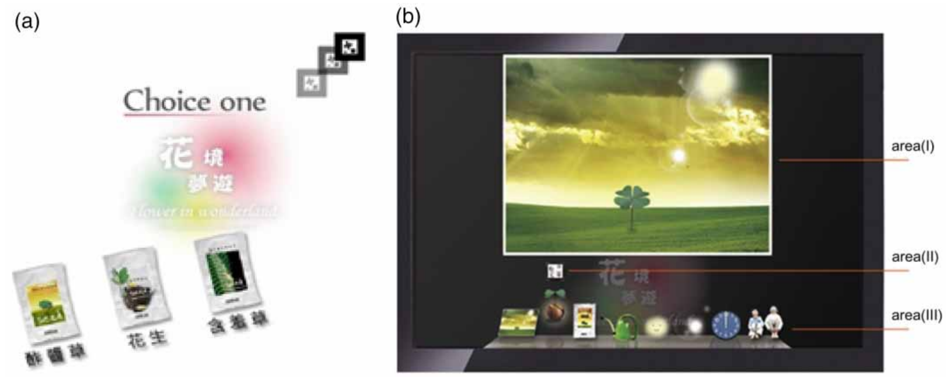

Figure 2. The ARFlora system interface. (a) System menu and (b) user interface.

Area (III) is an animated wizard providing students with interactive guidance by which to engage in learning.

Figure 3 shows an illustration of the use of the mechanical clock and microphone in the ARFlora system. In order to support students with the ability to operate the changes in time in the system, an animated virtual clock was designed that can be controlled by using the mechanical clock and the Arduino platform, as shown in Figure 3(a). Accordingly, students

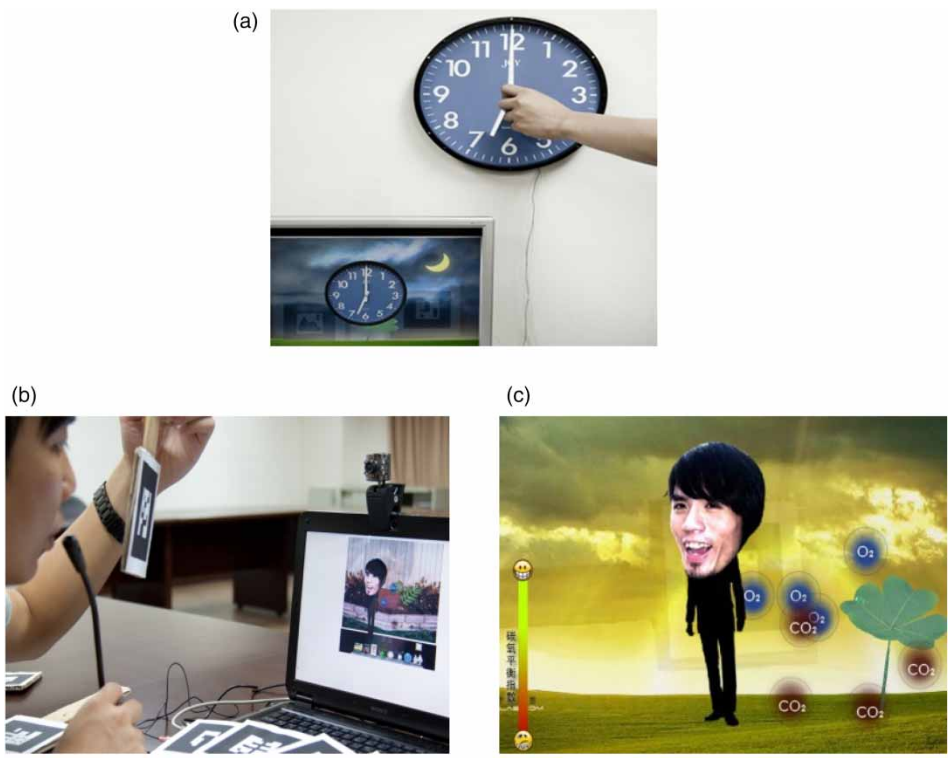

Figure 3. The illustration of the use of the mechanical clock and microphone. (a) Students adjust the mechanical clock to change the scene from day to night, (b) students breathe into the microphone to simulate the release of CO_2, and (c) the virtual plant performs photosynthesis and releases oxygen.

can adjust the mechanical clock to control the scene of the system from day to night so as to observe the growth of plants during both daytime and nighttime. Similarly, in order to support students with the ability to simulate the release of CO_2 in the system, the microphone was used. Specifically, students can breathe into the microphone, as shown in Figure 3(b), and then the system will sense the volume and convert it into an animation of the release of CO_2. Afterward, the system will display that the plant performs photosynthesis and releases oxygen, as shown in Figure 3(c). Overall, this learning experience is realistic and immersive, while the animations and visual effects make the learning more interesting.

Furthermore, in order to support student engagement in learning more realistically, elements of real-life situations are included to ensure that students can fully immerse in the learning and achieve further meaningful learning (Huang, Chiu, Liu, & Chen, 2011). Figure 4(a) shows an example of watering, in which students need to rotate the AR marker to simulate the action of watering. Similarly, when students plant flower seeds from seed packets, they also need to rotate the AR marker to simulate the action of pouring seeds from seed packets, as shown in Figure 4(b). Finally, students can also change the position of the AR marker to simulate a change in the direction of sunlight in order to understand the tropism of growth of plants.

3.2. *System demonstration*

The ARFlora system was developed to assist students in experiencing constructivist learning as it relates to the study of plants, in which they can manipulate virtual objects to learn and observe the growth of plants. Table 1 shows the design of a strengthening activity for learning about plants through the ARFlora system. The activity includes six stages, that is, seeding, watering, tropism, day and night changes, photosynthesis, and the relationship between plants and humans. In stage 1, students use the seeding marker to plant seeds from a seed packet in order to learn about the growth of plants starts from the sprouting of a seed. In stage 2, students use the watering marker to represent a bucket for the purpose of watering the seeds in order to learn that the source of nutrients in the growth of plants is water. In stage 3, students use the sun marker to change the direction of sunlight in order to learn the type of tropism in the growth of plants (e.g. phototropism). In stage 4, students use the clock marker to make time pass more quickly, and to operate the changes in time by adjusting the mechanical clock for the purpose of observing the changes in plants during daytime and nighttime (e.g. plants sleep at night; their leaves droop). In stage 5,

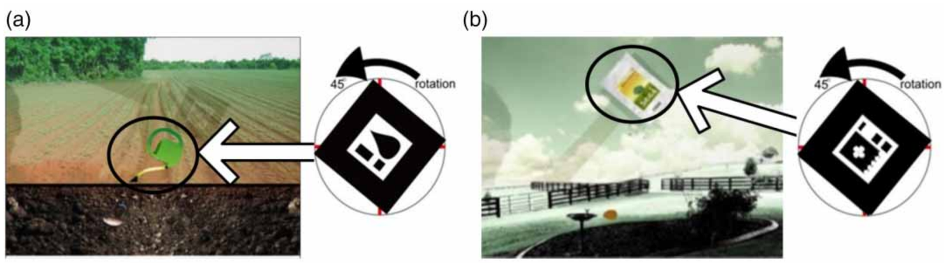

Figure 4. Student rotates AR maker to simulate real-life situations. (a) Student rotates AR maker to simulate the action of watering and (b) student rotates AR maker to simulate the action of pouring seeds from seed packets.

Table 1. The design of a strengthening activity to learn about plants.

Stage	Objective	Script	Scene	Manipulation
Stage 1: seeding	Learning about the growth of plants starting from the sprouting of seeds	Planting the seeds from seed packet by using the seeding marker		Seeding marker
Stage 2: watering	Learning the source of nutrient in the growth of plants	Using a bucket to water the seeds by using the watering marker		Watering marker
Stage 3: tropism	Learning the type of tropism in the growth of plants (e.g. phototropism)	Changing the direction of sunlight by using the sun marker		Sun marker
Stage 4: day and night changes	Observing the changes in plants during daytime and nighttime (e.g. plants sleep at night; their leaves droop)	Operating the changes in time by adjusting the mechanical clock and using the clock marker		 Mechanical clock; Clock marker
Stage 5: photosynthesis	Observing the process of photosynthesis	Observing the process of O_2 release when plants are exposed to sunlight by using the sun and photosynthesis markers		Sun marker; Photosynthesis marker
Stage 6: the relationship between plants and humans	Learning the relationship between plants and humans; that is, plants absorb CO_2 and release O_2, while humans breathe in O_2 and exhale CO_2	Making plants absorb CO_2 exhaled from humans and turning it into O_2 by breathing into the microphone and using the people markers		 Microphone; People marker

students use the sun and photosynthesis markers to observe the process of release of O_2 when plants are exposed to sunlight in order to observe the process of photosynthesis. In stage 6, the people marker enable microphone detect sound, and students can breathe into the microphone to make plants absorb CO_2 exhaled from humans and to turn it into O_2 so that they can learn the relationship between plants and humans; that is, plants absorb CO_2 and release O_2, while humans breathe in O_2 and exhale CO_2. Overall, through the ARFlora system, students can use the webcam to capture AR markers, utilize the mechanical clock to operate changes in time, and use the microphone to simulate the generation of CO_2. Then, virtual objects (e.g. the virtual plants) and animation (e.g. the photosynthesis of the virtual plants) will be rendered and presented on-screen according to the manipulation. Accordingly, students can fully engage in constructivist learning intended to help them study the growth of plants, and they can freely manipulate environmental settings to experience changes in the growth of plants under different conditions.

3.3. *Special features of system*

AR technology capitalizes on the concept of virtual–physical interaction, and this interaction does not rely on precise alignment between virtual and physical objects, but on the overall system interaction. The so-called virtual–physical interaction is more than simply touchscreen interaction, but the interactive fusion of virtual–physical environment and objects. Current AR systems often focus on how the changes in physical objects trigger the variations in virtual images. The learning system developed in this study is powered by AR technology, where hands-on operation is accentuated for learners to observe the changing process of virtual objects to achieve the learning effect, differentiating from conventional AR learning system that exploits superimposed virtual–physical objects. Table 2 illustrates the difference between conventional AR and the ARFlora system.

4. Research design

4.1. *Research question*

In this work, we used the concept of AR technology to develop the ARFlora system for supporting students' learning about plants, hence one of the purposes of this research is to compare the effectiveness of the ARFlora system and digital video on students' learning about plants. Although previous studies have revealed that AR technology is a helpful means by which to support learning in comparison to traditional instruction, there are a limited number of detailed empirical studies that compare the effectiveness of AR technology and other technologies on student learning. Among the studies of technology-assisted learning, digital video has been regarded as one of the most useful technologies. Video, a visual presentation of information, allows students to see real-world situations on a screen. For example, students are able to watch videos on the changes during the process of plant growth. Furthermore, according to the dual coding theory (Clark & Paivio, 1991; Schnotz, 2002), visual information has more significant impact on learning compared to plain words, because visualized information can be processed by both verbal associations and visual imagery, while words can only be processed by verbal associations. This implies videos can serve as an effective medium in strengthening students' learning on plants. Accordingly, our investigation was structured around the following research questions:

Table 2. The difference between conventional AR and the ARFlora system.

Items	Conventional AR	ARFlora system
Virtual environment or object	Uses 3D technology to design virtual objects, for example, characters, chemical changes, ecological content, or geometric patterns (Billinghurst et al., 2001; Hsiao et al., 2012; Kye & Kim, 2008; Wu et al., 2013)	Takes advantage of both 2D for scene graphics and 3D for generating virtual objects. For example: (1) Scenes (grasslands, daytime, nighttime, etc.) (2) Plant growth process (seeding, germination, photosynthesis, etc.) (3) Natural objects (sun, moon, air, water, etc.) (4) Tools (seed packets, watering can, clock, etc.)
Physical objects	Textbooks, cube blocks, picture cards, etc. (Azuma, 1997; Chen & Tsai, 2012; McKenzie & Darnell, 2003; Serio et al., 2013)	(1) Microphone (respiration, breathing process) (2) Mechanical clock (time variations)
Interactive mode	(1) Rotating or changing the angle of AR marker to observe object changes (Billinghurst et al., 2001; Kye & Kim, 2008) (2) Observation through head-mounted glasses (McKenzie & Darnell, 2003) (3) Superimposition with real-world objects (Billinghurst et al., 2001; Chen & Tsai, 2012; Hsiao et al., 2012; Kye & Kim, 2008; Wu et al., 2013)	Interaction with multiple AR markers through gestures and movements, such as: (1) pouring from seed packet to simulate sowing; (2) using a watering can to simulate the watering process; (3) using the sun AR marker and moving it to start photosynthesis; (4) adjusting a mechanical clock (time variation) to control the virtual clock and activate changes in scene and plant variations; and (5) using a microphone to simulate breathing, simulating the relationship between humans and plants

(1) Is the effectiveness of ARFlora system on students' learning achievement similar to that of digital video?
(2) Is the effectiveness of ARFlora system on students' retention of the knowledge acquired similar to that of digital video?
(3) Is the effectiveness of ARFlora system on students' learning motivation similar to that of digital video?

4.2. *Participants*

The participants in this experiment consisted of a total of 55 fourth-grade students from two elementary-school classes in Taiwan. Among them, 28 students from one class were designated as the experimental group, while 27 students from the other class were the control group. Table 3 presents the basic information of these participants. The students in the experimental group were taught using slides with the ARFlora system; that is, the teacher used the slides to teach the growth of plants, and then the students used the

Table 3. Demographic characteristics of the participants.

	Experimental group	Control group	Total
Boys	14	13	27
Girls	14	14	28
Total	28	27	55

ARFlora system to strengthen their knowledge about the growth of plants. The students in the control group were taught by slides with a video; that is, the teacher used the slides to teach the growth of plants, and then students watched the video to strengthen their knowledge about the growth of plants. To avoid the potential influence of different teachers, a variable in the experiment, both classes had the same teacher, who has many years of experience in teaching science.

4.3. *Measurement tools*

In this study, the measurement tools were a pre-test, a post-test, a delayed-test, and a questionnaire used to measure the learning motivation regarding the plant-related curriculum. Questions in the pre-test, post-test, and delayed post-test were designed by two science teachers with years of professional teaching experience. The purpose of the pre-test, containing five multiple-choice questions, was to measure the students' understanding on plant growth in the two classes, that is, to learn whether the two classes had similar level of understanding on plant growth. The students answered each question according to the correctness of the statement, where each correct answer was awarded one point, with a full score of five points. The post-test was designed to be similar to the pre-test. The delayed-test about the growth of plants contained nine multiple-choice items, in which students answered each question according to the correctness of the statement, and where each correct answer was awarded one point, with a full score of nine points. The questionnaire for learning motivation was modified from the measure developed by Yang, Chen, and Jeng (2010). It consisted of five items with a five-point rating scheme, as shown in Table 4. From the questionnaire, Cronbach's alpha value was measured at 0.72, demonstrating good and consistent internal reliability.

4.4. *Procedure*

Figure 5 shows the experimental design of this study. At the beginning of the learning activity, the students took the pre-test. After the pre-test, the two classes of students went through learning activities that lasted a total of 120 minutes, where they learned about the basics of plant growth, as a part of their original science curriculum. After the learning activity, the students in the experimental group used the ARFlora system to strengthen their level of knowledge about the growth of plants; that is, they used the ARFlora system to

Table 4. The questionnaire for learning motivation.

Item 1. I like the way the class is being taught today
Item 2. The way the class is taught draws my attention
Item 3. I think the teaching materials are diversified
Item 4. I have more understanding of the processes involved in plant growth
Item 5. I like the strengthening activity that helps me learn about the processes related to plant growth

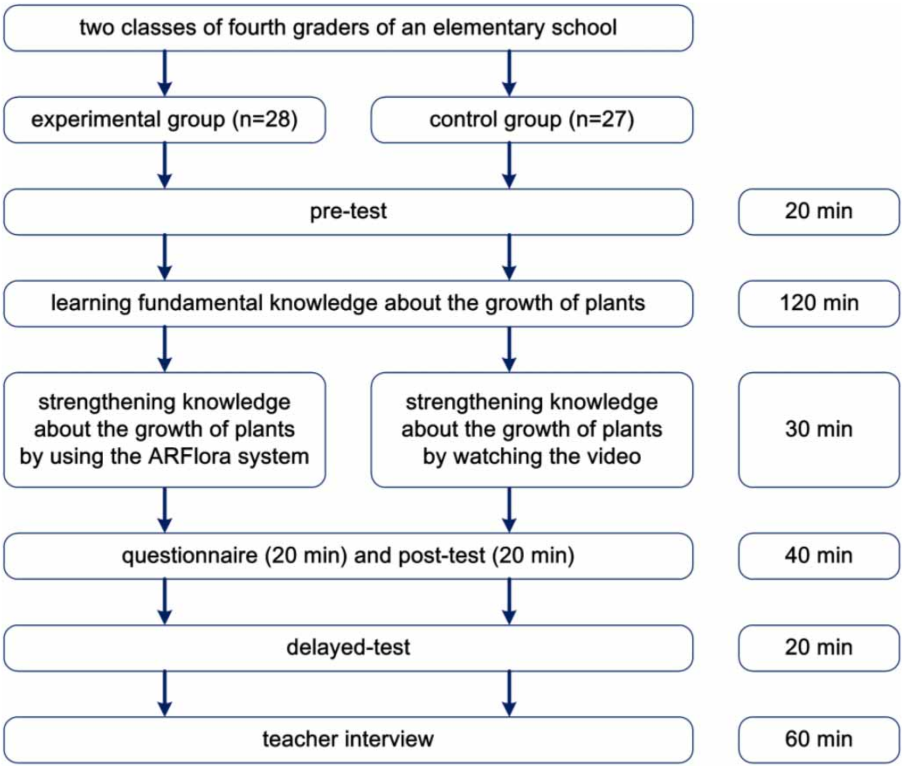

Figure 5. Diagram of the experimental design.

experience the learning activity, as shown in Table 1. On the other hand, those in the control group watched the video to strengthen their knowledge about the growth of plants. The time allowed for the students to strengthen knowledge was 60 minutes. Once the strengthening activity was completed, the students took the questionnaire and the post-test in order to measure their learning motivation and learning achievement. One week later, the delayed-test was given to both groups to measure the retention level of the strengthening activity. Finally, a teacher interview was used to investigate teacher perceptions toward the entire teaching and learning process.

4.5. *Variables*

The dependent variables of this study comprise both the learning achievement and the learning motivation of students, in which the pose-test, delayed-test, and the questionnaire were used to measure the variations of them. The independent variable of this study is the intervention of the strengthening activity. To operationalize the intervention, the students in the experimental group used the ARFlora system to carry out the strengthening activity, while others in the control group watched the video to achieve the strengthening activity. The primary control variable of this study is the teaching experience of teachers; because the years of teaching experience may influence the effectiveness of teaching and further to affect both the learning achievement and the learning motivation of students. To avoid the threat of the teaching experience in experimental results, both classes had the same teacher.

5. Results and discussion

In this study, due to the fact that the sample is small size and non-normal distribution, Mann–Whitney *U* test was applied to conduct data analyses. In contrast with *t*-test, the Mann–Whitney *U* test does not require large samples and normal distribution. Hence, the Mann–Whitney *U* was used instead of the *t*-test.

5.1. *Analysis of learning achievement*

Prior to the learning activities, participating students were subjected to a pre-test to assess their basic knowledge on plant growth. Table 5 shows the Mann–Whitney *U* test results for the pre-test, where the mean and standard deviation was 3.10 and 1.03 in the experimental group, respectively, and 3.14 and 1.29 in the control group. The Mann–Whitney *U* test results showed that no significant difference existed between the two groups in the pre-test ($p = .88 > .05$), implying the two groups of students had similar level of understanding on plant growth prior to the experiment.

After the learning activities and strengthened exercises, the Mann–Whitney *U* test was used to test the difference in post-test scores between the two groups. Table 6 shows the results, where the test scores in the experimental group (mean = 3.96, SD = .79) were not significantly higher ($p = .16 > .05$) than the control group (mean = 3.62, SD = .92). This result indicated that compared to videos, AR technology is not particularly helpful in assisting students in enhancing their knowledge in plant growth.

Moreover, the similar result of the post-test could also be found in Figure 6, which showed the relationships between pre-test and post-test values of the two groups. From this figure, it could be observed that there is not a significant difference in the relationships of the two groups. The result of Figure 6 can echo the result of the post-test, that is, AR technology is unable to significantly enhance the knowledge of students in plant growth as compared with videos.

One week after the post-test, the delayed-test was conducted to compare the retention of the knowledge acquired for the two groups of students. Table 7 shows the Mann–Whitney *U* test results for the delayed-test. The students in the experimental group had significantly better retention levels than those in the control group ($p = .00 < .05$), implying that compared with digital video, AR technology was particularly helpful with regard to assisting students in retaining their knowledge in terms of learning about the growth of plants.

From the results of the post-test and delayed-test, we observed two phenomena. The first phenomenon was that the applications of AR technology and digital video almost had the same effectiveness on student learning achievement (see the results for the post-test). That is to say, the answer to the first research question was that the effectiveness of AR technology

Table 5. Mann–Whitney *U* test result of the pre-test.

				95% confidence interval			
	N	Mean	SD	Lower	Upper	*p*	Cohen's *d*
Experimental group	28	3.10	1.03	2.70	3.50	.88	.03
Control group	27	3.14	1.29	2.63	3.65		

Table 6. Mann–Whitney *U* test result of the post-test.

	N	Mean	SD	95% confidence interval Lower	95% confidence interval Upper	*p*	Cohen's *d*
Experimental group	28	3.96	0.79	3.65	4.27	.16	.39
Control group	27	3.62	0.92	3.26	3.99		

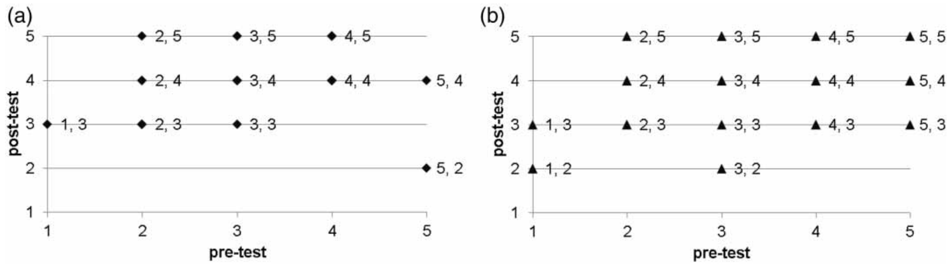

Figure 6. The relationships between pre-test and post-test values of the two groups. (a) Experimental group and (b) control group.

Table 7. Mann–Whitney *U* test result of the delayed-test.

	N	Mean	SD	95% confidence interval Lower	95% confidence interval Upper	*p*	Cohen's *d*
Experimental group	28	7.53	1.31	7.02	8.04	.00	.12
Control group	27	6.07	1.29	5.56	6.58		

on students' learning achievement is similar to that occurring with the use of digital video. The second phenomenon was that AR technology was particularly helpful with regard to assisting students in retaining acquired knowledge in comparison with digital video. That is to say, the answer to the second research question was that the effectiveness of AR technology on the retention of acquired knowledge is more significant than that of digital video.

5.2. *Analysis of learning motivation*

After the learning activity, the two groups of students took the questionnaire on learning motivation. Their responses to the questionnaire for learning motivation are summarized in Table 8. The results as shown indicate that students in the experimental group rated most items higher than those in the control group, though they were a relatively moderate effect size. Accordingly, compared with digital video, AR technology was particularly useful to stimulate students toward the study of plants.

Table 9 shows the percentage of students who expressed for each item. In the experimental group, 89% of students indicated that they liked the way the class was taught using the ARFlora; 75% of students pointed out that they could concentrate in the class by using ARFlora; 89% of students responded that they thought the teaching materials

Table 8. Descriptive statistics for the results of the learning motivation questionnaire.

Items	Experimental group		Control group		
	Mean	SD	Mean	SD	Cohen's *d*
Item 1. I like the way the class is being taught today	4.29	0.66	3.89	0.93	.49
Item 2. The way the class is taught draws my attention	4.11	0.88	3.81	1.00	.31
Item 3. I think the teaching materials are diversified	4.29	0.66	3.78	0.80	.69
Item 4. I have more understanding of the processes involved in plant growth	4.25	0.75	3.93	0.87	.39
Item 5. I like the strengthening activity that helps me learn about the processes related to plant growth	4.21	0.83	3.85	0.91	.41

Table 9. The analysis of the percentage of students who expressed.

Items	Groups	Strongly agree (%)	Agree (%)	Undecided (%)	Disagree (%)	Strongly disagree (%)
Item 1	Experimental group	39	50	11	0	0
	Control group	25	46	14	11	0
Item 2	Experimental group	39	36	21	4	0
	Control group	29	32	25	11	0
Item 3	Experimental group	39	50	11	0	0
	Control group	14	54	21	7	0
Item 4	Experimental group	39	50	7	4	0
	Control group	25	46	18	7	0
Item 5	Experimental group	43	39	14	4	0
	Control group	21	50	14	11	0

are diversified; 89% of students indicated that they had more understanding of the processes involved in plant growth through the ARFlora; 82% of students pointed out that they liked the strengthening activity that helps them learn about the processes related to plant growth. In comparison, the corresponding answers for the aforementioned items in the control group were lower at 71%, 61%, 68%, 71% and 71%, respectively.

Table 10 shows the Mann–Whitney *U* test results from the learning motivation questionnaire between the two groups. The results showed that learning motivation in the experimental group was significantly higher than that in the control group ($p = .00 < .05$), suggesting AR technology, compared to videos, has a significant impact on enhancing students' motivation to learn about plant growth. That is to say, the answer to the third research question is that the effectiveness of AR technology on students' learning motivation is more significant than that of digital video.

Table 10. Mann–Whitney *U* test results for the learning motivation questionnaire.

				95% confidence interval			
	N	Mean	SD	Lower	Upper	*p*	Cohen's *d*
Experimental group	28	4.22	0.47	4.04	4.41	.00	.71
Control group	27	3.85	0.56	3.62	4.07		

5.3. *Discussion*

The results of the post-test indicated that AR technology and digital video have the same effectiveness on students' learning achievement, but on the other hand, the results of the delayed-test indicated that the effectiveness of AR technology on retention of the knowledge acquired is more significant than that occurring with the use of digital video. The human memory system could be used to explain the possible reason for these differences. The human memory system comprises three types of memory, including sensory memory, short-term memory, and long-term memory (Atkinson & Shiffrin, 1968; Chang, Kinshuk, Chen, & Yu, 2012), as shown in Figure 7. When information from the environment enters the mind through the senses, sensory memory serves as a buffer to receive the input information. Afterward, information is passed from sensory memory into short-term memory as a result of attention. Finally, the short-term memory processes the information and then stores it into the long-term memory by repeated rehearsal of the information. Hence, we can observe that short-term memory is based on attention, while long-term memory is based on rehearsal. That is to say, when technology can draw the attention of students, it can assist students in storing the knowledge acquired in the short-term memory; while technology can provide students with an opportunity for rehearsal, it can also assist students in storing the knowledge acquired in the long-term memory. Similarly, cognitive load theory (Sweller, 1988; Sweller, van Merriënboer, & Paas, 1998) also could be used to interpret this situation. Cognitive load means that how much effort is required when an individual attempts to understand and perform a task (Huang, Liu, & Tsai, 2013). Cognitive load can be divided into three types: intrinsic, extraneous, and germane (Sweller, 1988; Sweller et al., 1998). Intrinsic cognitive load is affected by the inherent nature of the materials; extraneous cognitive load is determined by an improper instructional design; germane cognitive load is caused by an appropriate instructional design and has been shown to be beneficial to learning (Huang et al., 2013). This means that an appropriate instructional design can be used to support students engaging in the processing and constructing knowledge, and then store them in their long-term memory (Kolfschoten, Lukosch, Verbraeck, Valentin, & Vreede, 2010; Sweller et al., 1998). In this study, both AR technology and digital video have the ability to attract the attention of students toward the study of plants; however, digital video is incapable of providing students with an opportunity for rehearsal. Accordingly, only AR technology can specifically assist students in retaining their acquired knowledge. That is to say, AR technology can be used to promote the germane cognitive load of students, and then help them to store the knowledge in their long-term memory. Evidence gathered from the teacher interviews helped to interpret the results. The teacher mentioned that the use of the ARFlora system resulted in knowledge about the growth of plants that was not just simply transmitted through teacher or digital video, but rather constructed in the mind of the students

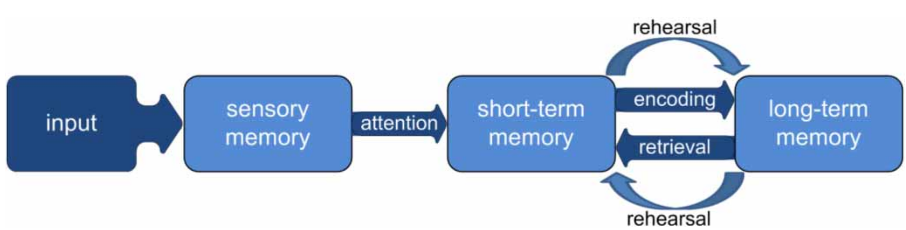

Figure 7. The human memory system.

through their practice. The results echoed the studies of Hsiao et al. (2012), Harel and Papert (1991), and Palincsar (1998). Hsiao et al. (2012) indicated that AR technology is useful to construct an environment to support students in experiencing learning by doing. Harel and Papert (1991) and Palincsar (1998) pointed out that knowledge is constructed by students who are involved in active learning rather than in knowledge simply transmitted from teacher to students. Consequently, it can be concluded that AR technology can assist students in retaining acquired knowledge in comparison to digital video.

Findings from the learning motivation questionnaire showed that AR technology outperforms videos in enhancing students' learning motivation. Additional supporting evidence can be observed in student's behavior in the classroom. During the experiment, many students were amazed by the freedom of using the ARFlora system to manipulate virtual objects (e.g. watering plants or providing sunlight) and observe the changes in plant growth. On a more important note, students' curiosity was observably induced through the use of the ARFlora system, as can be evidenced from students' excitement when using the system to really focus on learning the process of plant growth. In addition, the results of the teacher interview also helped in the interpretation of the results. The teacher mentioned that the design of the ARFlora system drew the students' attention, where the image content on the computer screen changed through different operations, spurring their curiosity in wanting to try and have hands-on practice. The above student behavior explains the results and echos the studies of Chen and Tsai (2012), Hsiao et al. (2012), Serio, Ibáñez, and Ibáñez (2013), and Sotiriou and Bogner (2008). Chen and Tsai (2012) indicated that AR technology for instruction is indeed helpful in promoting student motivation and willingness to learn under conditions in which students are obviously very satisfied with the use of AR technology for instruction. Hsiao et al. (2012) revealed that AR technology can be used to usefully promote students' interest and motivation to study harder as it can supply them with a lot of fun. Serio et al. (2013) concluded that the impact of AR technology on motivation involves students achieving higher levels of engagement in learning activities with less cognitive effort. Sotiriou and Bogner (2008) pointed out that AR technology can assist students in advancing their skills and support them to acquire more deep knowledge. More importantly, AR technology could be used to construct a guided discovery learning context in this study. This learning context supplies students with a simulation model that is not directly visible to them, in which they have to engage in discovery activity in order to learn the growth of plants. During the discovery activity, students explore the simulation model by manipulating virtual objects such as sunlight and observing the changes in plant growth. It is expected that students can acquire a deeper understanding of plant growth and can transfer their knowledge to similar 'problems' in real situations (Meij & Jong, 2006). In addition, compared to AR technology, digital video is directly visible to students, so that they cannot experience learning by doing and further cannot attract their attention. This explanation can echo the study of Clark (1994). Clark argued that media do not influence learning or motivation; rather, "learning is caused by the instructional methods embedded in the media presentation." Consequently, it can be concluded that AR technology is useful to motivate student involvement in the study of plants in comparison to digital video.

6. Conclusions

Our research applied the AR technique, as well as hardware and software to develop an ARFlora system, which assisted students in learning about changes in the growth of plants. To explore the effectiveness of the ARFlora system on student knowledge of plants in comparison to digital video, a quasi-experimental research design was constructed. The results revealed that the ARFlora system and digital video have the same effectiveness on students' learning achievement, but the ARFlora system can specifically assist students in retaining their acquired knowledge in comparison to digital video. In addition, the ARFlora system is particularly useful with regard to motivating students to be more involved in the study of plants in comparison to digital video.

Although the proposed ARFlora system demonstrated significant effectiveness in improving the student knowledge about plant growth, some limitations with regard to the use of this system need to be noted. First, researchers have indicated that both AR technology and digital video have the same ability to improve the learning achievements of students; that is, if teachers simply want to improve their learning achievements, digital video might be a better choice. This is because, compared with the implementation of an AR educational system, digital video is easy to implement in classrooms. Secondly, the development of an educational AR system is very time consuming. As a solution to this problem, we are planning to develop a modular AR system for education, so that researchers can easily use the module to develop their own educational applications. In addition, we are in the process of applying the system in this study in different units in the science curriculum, such as the butterfly life cycle, and probing into the effects of cognitive modes and learning styles on learning achievement or motivation.

Finally, we did not exploit the full potential of AR technology, which is underpinned by presentation of 3D virtual objects in the context of real environments and direct manipulation of the presented content by users. The focus of this current study is to explore the application of AR technology for class learning. In this study, a virtual eco-learning context was constructed, in which AR technology was used to support students in manipulating various virtual objects and observing the changes in plant growth. In the future work, we will integrate virtual information into the real-world circumstances and hence the application of AR technology will provide students with outdoor learning experiences.

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References

Arvanitis, T. N., Petrou, A., Knight, J. F., Savas, S., Sotiriou, S., Gargalakos, M., & Gialouri, E. (2009). Human factors and qualitative pedagogical evaluation of a mobile augmented reality system for science education used by learners with physical disabilities. *Personal and Ubiquitous Computing*, *13*(3), 243–250.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposal system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (pp. 89–195). New York, NY: Academic Press.

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

Banzi, M. (2008). *Getting started with Arduino*. Sebastopol, CA: O'Reilly & Associates.

Bebbington, A. (2005). The ability of a-level students to name plants. *Journal of Biological Education*, *39*(2), 63–67.

Billinghurst, M., Kato, H., & Poupyrev, I. (2001). The MagicBook: Moving seamlessly between reality and virtuality. *IEEE Computer Graphics and Applications*, *21*(3), 6–8.

Chang, T. W., Kinshuk, Chen, N. S., & Yu, P. T. (2012). The effects of presentation method and information density on visual search ability and working memory load. *Computers & Education*, *58* (2), 721–731.

Chen, C. M., & Tsai, Y. N. (2012). Interactive augmented reality system for enhancing library instruction in elementary schools. *Computers & Education*, *59*(2), 638–652.

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|. doi:10.1007/s10956-012-9405-9

Chu, H. C., Hwang, G. J., Tsai, C. C., & Tseng, J. C. R. (2010). A two-tier test approach to developing location-aware mobile learning systems for natural science courses. *Computers & Education*, *38*(1–3), 241–252.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review*, *3*(3), 149–210.

Clark, R. E. (1994). Media will never influence learning. *Educational Technology Research and Development*, *42*(2), 21–29.

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.

Flannery, M. C. (2002). Do plants have to be intelligent? *The American Biology Teacher*, *64*(8), 628–633.

Girvan, C., Tangney, B., & Savage, T. (2013). SLurtles: Supporting constructionist learning in second life. *Computers & Education*, *61*, 115–132.

Harel, I., & Papert, S. (Eds.). (1991). *Constructionism*. Norwood, NJ: Ablex.

Hoekstra, B. (2000). Plant blindness – the ultimate challenge to botanists. *The American Biology Teacher*, *62*(2), 82–83.

Hsiao, K. F., Chen, N. S., & Huang, S. Y. (2012). Learning while exercising for science education in augmented reality among adolescents. *Interactive Learning Environments*, *20*(4), 331–349.

Huang, Y. M., Chiu, P. S., Liu, T. C., & Chen, T. S. (2011). The design and implementation of a meaningful learning-based evaluation method for ubiquitous learning. *Computers & Education*, *57*(4), 2291–2302.

Huang, Y. M., Huang, Y. M., Liu, C. H., & Tsai, C. C. (2013). Applying social tagging to manage cognitive load in a Web 2.0 self-learning environment. *Interactive Learning Environments*, *21* (3), 273–289.

Huang, Y. M., Lin, Y. T., & Cheng, S. C. (2010). Effectiveness of a mobile plant learning system in a science curriculum in Taiwanese elementary education. *Computers & Education*, *54*(1), 47–58.

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

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), 163–174.
Kirner, C., & Zorzal, E. R. (2005). *Educational applications of augmented reality collaborative environments*. Proceedings of sixteenth Brazilian symposium on Informatics in Education, Porto Alegre, Brazil, pp. 114–124.
Kolfschoten, G., Lukosch, S., Verbraeck, A., Valentin, E., & Vreede, G. J. D. (2010). Cognitive learning efficiency through the use of design patterns in teaching. *Computers & Education*, *54*(3), 652–660.
Kye, B., & Kim, Y. (2008). Investigation of the relationships between media characteristics, presence, flow, and learning effects in augmented reality based learning. *International Journal for Education Media and Technology*, *2*(1), 4–14.
Liu, T. Y., Tan, T. H., & Chu, Y. L. (2009). Outdoor natural science learning with an RFID-supported immersive ubiquitous learning environment. *Educational Technology & Society*, *12*(4), 161–175.
Martín-Gutiérrez, J., Contero, M., & Alcañiz, M. (2010). Evaluating the usability of an augmented reality based educational application. In V. Aleven, J. Kay, & J. Mostow (Eds.), *Intelligent tutoring systems, Pittsburgh, PA, USA*, Lecture Notes in Computer Science (Vol. 6094, pp. 296–306). Berlin, Heidelberg: Springer-Verlag.
McKenzie, J., & Darnell, D. (2003). *The eyeMagic book: A report into augmented reality storytelling in the context of a children's workshop 2003*. Retrieved December 5, 2012, from http://www.mindspacesolutions.com/demos/eyeMagicWorkShopReport.pdf
Meij, J. V. D., & Jong, T. D. (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction*, *16*(3), 199–212.
Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review Psychology*, *49*, 345–375.
Schnotz, W. (2002). Towards an integrated view of learning from text and visual displays. *Educational Psychology Review*, *14*(1), 101–120.
Schussler, E. E., & Olzak, L. A. (2008). It's not easy being green: Student recall of plant and animal images. *Journal of Biological Education*, *42*(3), 112–119.
Serio, Á. D., Ibáñez, M. B., & Ibáñez, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Computers & Education*. doi:10.1016/j.compedu.2012.03.002
Silva, H., Pinho, R., Lopes, L., Nogueira, A. J. A., & Silveira, P. (2011). Illustrated plant identification keys: An interactive tool to learn botany. *Computers & Education*, *56*(4), 969–973.
Sotiriou, S., & Bogner, F. X. (2008). Visualizing the invisible: Augmented reality as an innovative science education scheme. *Advanced Science Letters*, *1*, 114–122.
Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285.
Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251–296.
Tsai, C. C., Lin, S. S. J., & Yuan, S. M. (2001). Students' use of web-based concept map testing and strategies for learning. *Journal of Computer Assisted Learning*, *17*(1), 72–84.
Tsai, C. C., Lin, S. S. J., & Yuan, S. M. (2002). Developing science activities through a networked peer assessment system. *Computers & Education*, *38*(1–3), 241–252.
Wandersee, J. H., & Schussler, E. E. (2001). Toward a theory of plant blindness. *Plant Science Bulletin*, *47*(1), 2–9.
Woods, E., Billinghurst, M., Looser, J., Aldridge, G., Brown, D., Garrie, B., & Nelles, C. (2004). *Augmenting the science centre and museum experience*. Proceedings of the 2nd international conference on computer graphics and interactive techniques in Australasia and South East Asia, Singapore, pp. 230–236.
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 & Education*, *62*, 41–49.
Yang, J. C., Chen, C. H., & Jeng, M. C. (2010). Integrating video-capture virtual reality technology into a physically interactive learning environment for English learning. *Computers & Education*, *55*(3), 1346–1356.