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Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations

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Augmented reality (AR) has been recognized as a potential technology to help students link what they are observing in the real world to their prior knowledge. One of the most challenging issues of AR-based learning is the provision of effective strategy to help students focus on what they need to observe in the field. In this study, a competitive gaming approach is proposed to support AR-based learning activities conducted in real-world contexts. An experiment has been conducted on an elementary school ecology course to explore the effectiveness of the proposed approach in comparison with the conventional AR-based mobile learning approach in field trips. The experimental results show that the AR-based gaming approach can improve not only students' learning attitudes, but also their learning performance on the field trip. Accordingly, discussions and some suggestions for future work are provided.

Keywords: educational computer games; digital game-based learning; augmented reality; ecology courses

Introduction

Situating students in real-world learning environments for ecology observations has been emphasized by educators in the past decades (Hung, Hwang, Su, & Lin, 2012; Hwang & Chang, 2011; Vogel, Kurti, Milrad, Johansson, & Müller, 2014). The rapid advancement of mobile and wireless network technologies has provided opportunities to offer learning support to individual students in the field (Hou et al., 2014; Looi & Wong, 2014) and has been recognized as a potential approach to facilitating students' learning on field trips (Chu, Hwang, & Tsai, 2010; Hwang, Tsai, & Yang, 2008). However, educators have indicated that it is improper to rely on technologies to improve students' learning performance; instead, it is necessary to adopt suitable learning strategies or tools to support students while on field trips (Hwang, Wu, & Ke, 2011; Peng et al., 2009). Chu (2014) further reported the possible negative effects of using mobile technologies on field trips; that is, without carefully integrating the digital learning content with the real-world environment, students' cognitive load could be very heavy, and hence their learning achievements and attitudes could be disappointing.

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In the meantime, challenges have been considered as an important element that attracts students' full attention to engage in learning activities (Inal & Cagiltay, 2007). Among various learning approaches, digital game-based learning has been recognized as a promising approach for making positive impacts on students' learning perceptions via engaging them in challenging tasks (Marty & Carron, 2011; Minović, Milovanović, & Starčević, 2011; Yang, 2012). In particular, competition has been indicated by researchers as being an effective strategy for engaging students in challenging activities (Connolly, Stansfield, & Hainey, 2007; Green & McNeese, 2007; Hwang, Wu, & Chen, 2012). Therefore, in this study, an AR-based gaming approach is proposed to improve students' learning attitude as well as their learning achievements on field trips. To evaluate the performance of the proposed approach, an experiment has been conducted in an elementary school ecology course to investigate the following research questions:

(1) Can the augmented reality (AR)-based mobile game improve students' learning attitudes in mobile learning activities?
(2) Can the AR-based mobile game improve students' learning performances in mobile learning activities?

Literature review

Augmented reality

AR is a technology that enables the integration of real-world experience with digital world content (Azuma et al., 2001; Bujak et al., 2013). Via enabling the cooperation between real and virtual objects, this technology can provide learners with more realistic and immersive experience than virtual technology (Chiang, Yang, & Hwang, 2014; Squire & Klopfer, 2007).

In recent years, researchers have tried to apply AR technology to educational settings (Cuendet, Bonnard, Do-Lenh, & Dillenbourg, 2013; Radu, 2014; Santos et al., 2014). For example, Wang, Duh, Li, Lin, and Tsai (2014) applied an AR-based simulation system to a collaborative inquiry-based learning activity in a science course and found that AR-based simulation could engage the students in the inquiry activity more thoroughly than the tradition simulation could. Fonseca, Martí, Redondo, Navarro, and Sánchez (2014) conducted a learning activity to engage students in developing visualized 3D architecture models using AR technology in an architecture and building engineering course. Jee, Lim, Youn, and Lee (2014) further developed an authoring tool for AR-based learning applications. It is apparent that AR technology has attracted much attention from educators and researchers.

On the other hand, researchers have attempted to employ AR technology in outdoor observations (EI Sayed, Zayed, & Sharawy, 2011; Perez-Sanagustin, Hernandez-Leo, Santos, Delgado Kloos, & Blat, 2014). For example, Kamarainen et al. (2013) reported the EcoMOBILE project, which integrated AR and probe technologies to support field trips in an environmental education course. Zhang, Sung, Hou, and Chang (2014) developed an AR-based armillary sphere for astronomical observation instruction. In the same year, Chiang, Yang, and Hwang (2014) also presented an AR-based mobile learning system for conducting in-field observation activities for a natural science course. From those educational applications, it is found that AR technology has great potential to provide effective learning support for in-field observation activities. Klopfer (2008) further indicated the potential of using the AR technology in developing mobile educational games.

Digital game-based learning

Researchers have indicated the effectiveness of digital game-based learning, which incorporates learning content into computer games for engaging students in gaming scenarios associated with educational objectives (Kiili, 2005; Lin et al., 2013; Prensky, 2007). In the past decade, the number of digital game-based learning studies and applications has increased at a rapid pace (Liu, Lee, & Chen, 2013), showing the potential of the approach. In an educational computer game, there are usually clear rules and challenging objectives, such that students are eager to complete the gaming missions and hence ignore changes in the surroundings as well as their anxiety and worries, which results in deeper immersion in learning (Csikszentmihalyi, 1975; Prensky, 2007; Psotka, 2013). Several studies have reported that digital game-based learning could be a more effective teaching tool, in terms of motivating students to learn in complex learning processes, than traditional instruction (Charles & McAlister, 2004; Papastergiou, 2009; Squire, 2005; Sung & Hwang, 2013).

Researchers have also reported the potential of employing educational computer games in helping students improve their learning performance (Brom, Preuss, & Klement, 2011; Huang, Huang, & Tschopp, 2010; Wang & Chen, 2010). Some studies have indicated that digital games are an important part of the development of children's cognition and social processes (Kim, Park, & Baek, 2009; Yien, Hung, Hwang, & Lin, 2011); some studies have also reported that educational computer games can enhance students' learning interest (Ebner & Holzinger, 2007; Malone, 1980), and further increase their learning motivation (Burguillo, 2010; Harris & Reid, 2005). For instance, Miller, Chang, Wang, Beier, and Klisch (2011) developed a multimedia science game and found a positive relationship between role-play experiences and science career motivation. Kim, Park, and Baek (2009) have indicated that games are an important part of the development of children's cognition and social processes. In addition, several researchers have attempted to apply digital games to learning activities using mobile technologies (Chen, Shih, & Ma, 2014; Lu, Chang, Kinshuk, Huang, & Chen, 2014). For example, Sintoris et al. (2010) developed a mobile game for engaging children in learning tasks in a historical museum. Liu and Chu (2010) reported an English learning activity in which students learned with digital games via mobile devices. These studies have revealed the potential of applying educational computer games to in-field learning activities.

Among the factors affecting learners' motivation in game participation, challenge has been identified as the top ranking factor (Connolly, Stansfield, & Hainey, 2007; Moreno, 2012). Competition has also been recognized as an important feature in game development since it is able to bring additional challenges which attract players' attention and motivate them (Burguillo, 2010). Researchers have indicated that a competitive game has good potential to make players more willing to accept challenges and engage in the gaming missions (Moreno, 2012). Several studies have also reported that moderate competition in educational computer games could increase students' feeling of enjoyment, intention to use and self-esteem (Chen, 2014; van Eck & Dempsey, 2002; Kazakova, Cauberghe, Pandelaere, & Pelsmacker, 2014). Consequently, in this study, an AR-based gaming approach is proposed to support in-field mobile learning. It is expected that, via adding the gaming feature, students' learning achievement and attitudes can be improved when supported by the AR technology in the field.

Development of an AR-based competitive game

The AR-based mobile game was developed using ASP.Net and SQL server. In this study, the authentic learning environment is a butterfly garden consisting of 10 butterfly ecology areas, in which different species of butterflies and their host plants are raised. A location-aware real-world learning environment is established by setting up wireless communication networks in the garden by installing a QR-code tag to each learning target (i.e. the butterfly ecology area). When learning in this environment, each student holds a smartphone equipped with a camera, with which the learning system is able to detect the location of the students, guide them to find the target ecology areas and show them the corresponding learning tasks or related learning materials.

System framework and functions

Figure 1 shows the structure of the AR-based competitive game, which is developed in the form of a board game. It consists of a board game interface, a learning management mechanism, a learning guidance mechanism and a gaming mechanism; moreover, several databases (i.e. a student profile database, a learning portfolio database, a mini-game database and a learning material database) are established to provide learning supports for individual students.

The board game interface is designed for presenting the gaming status and gaming missions. The basic form of the game is a board consisting of several sequential locations, each of which represents a gaming mission (i.e. a learning task). Players are asked to throw a dice to move sequentially based on the number shown on the top of the dice. The main difference between the proposed game and a traditional board game is that the players in this game need to move around the real-world environment and find answers to the questions raised in the game via making observations in the real-world environment; moreover, they need to face some immediate challenges presented via the AR technology in the

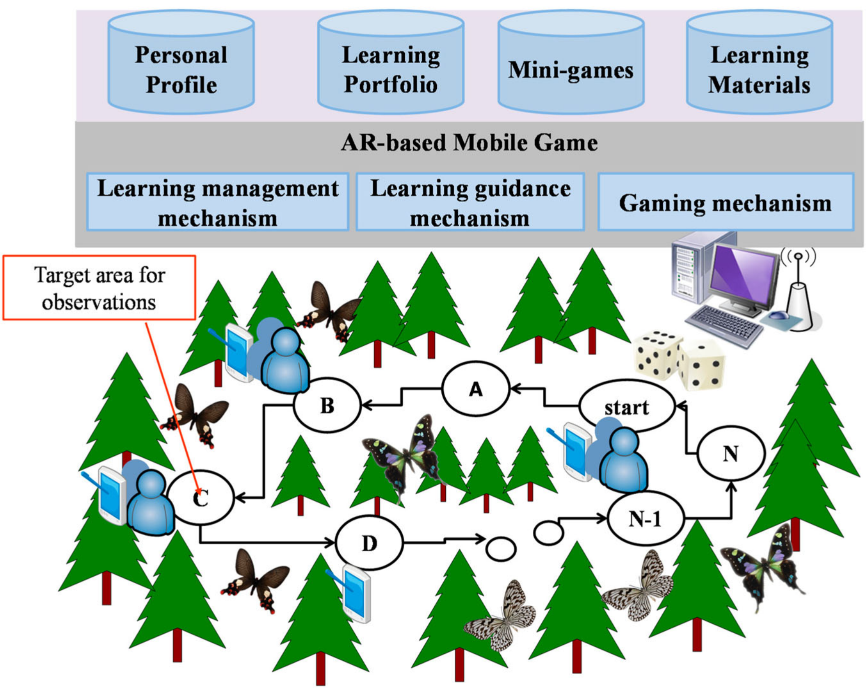

Figure 1. System structure of the AR-based mobile game.

target location during the gaming process. The learning management mechanism is used by the teacher or researchers for providing the gaming content and managing the players' accounts.

The gaming mechanism is used to count the scores of the players based on their gaming status. For example, players who correctly answer a question for the first, second and third time will get the full score, half score and no score, respectively.

The learning guidance mechanism is used to guide the players to make further observations in the field when they fail to correctly answer a question during the gaming process. Assume that a student fails to answer a question related to the feature of a target butterfly host plant by giving an incorrect answer A' when the correct answer should be A. The learning guiding mechanism then provides the supplementary materials of another plant with feature A' and ask the student to make further observations and comparisons. Following that, the student is asked to answer the question again. If the student fails to correctly answer the question the second time, the learning system then presents the correct answer and the link for accessing the details of the learning target.

Interfaces of the AR-based competitive game

Figure 2 shows the main gaming interfaces. During the gaming process, individual students need to determine their movement scale (i.e. 1 to 6) via throwing a dice. In each location in the field of the game board, there is a set of gaming missions; moreover, the player's current score and the top 10 players' scores are presented on the screen, so that the students know their gaming status in comparison with others, as shown in Figure 2(a). When students arrive at a specific location in the field, the missions in the corresponding set are triggered in turn and presented using AR technology. Figure 2(b) shows an illustrative example of a gaming mission, which asks the students to observe the imago of a specified butterfly. A gaming mission can be a multiple-choice question of the observing activity in the field or a mini-game to present the supplementary materials. The questions are presented in a pre-defined order to the students when they trigger the gaming missions related to "a barrier to overcome" on the board.

On the other hand, when the students move to the locations in the field that are related to "an opportunity to win," they are asked to play a mini-game concerning the supplementary materials. The mini-games could be a matching game or an AR-based shooting game developed based on the learning content presented to the students. The shooting game aims to

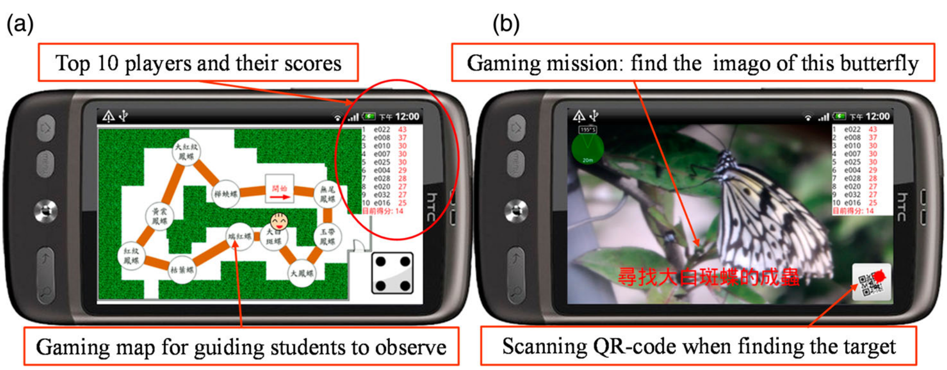

Figure 2. User interface of the AR-based competitive game.

Figure 3. Illustrative example of an AR-based shooting game.

help students recognize the predators or natural enemies of the butterflies by combining real-world contexts (i.e. the butterfly ecology area) and virtual targets (i.e. the predators or enemies of the butterflies). The matching game aims to help students comprehend the relationships between butterflies and the host plants of butterflies. When correctly connecting individual butterflies with their host plants, the gaming score is increased. In the example shown in Figure 3, the information related to the predators or natural enemies of the butterflies is not presented explicitly; instead, the students need to find the relationships between the natural enemies and butterflies during the shooting missions (i.e. when facing natural enemies, the weapons become useless).

Experiment design

To evaluate the efficacy of the proposed approach, an experiment was conducted to compare the learning outcomes of the students who learned with the AR-based mobile game and those who learned with the AR-based mobile learning approach. The authentic learning environment is a butterfly ecology garden located in southern Taiwan. The in-field learning activity was part of the regular natural science curriculum in the selected school. It aimed at helping students learn the ecology of butterflies, including the growing cycle, appearance features, natural enemies and host plants of different species of butterfly.

Participants

The participants were two classes of the fifth graders taught by the same teacher. Their average age was 11. One class was randomly selected as the experimental group ($n=30$), and the other class was the control group ($n=27$).

Treatments

Figure 4 shows the procedure of the experiment. In the first stage, both groups of students learned the basic knowledge of the buttery ecology and received instructions for operating the AR-based mobile learning system. Following that, the students took a pretest and completed the pre-questionnaires in 30 minutes for analyzing their knowledge of and attitudes towards butterfly ecology before participating in the field trip.

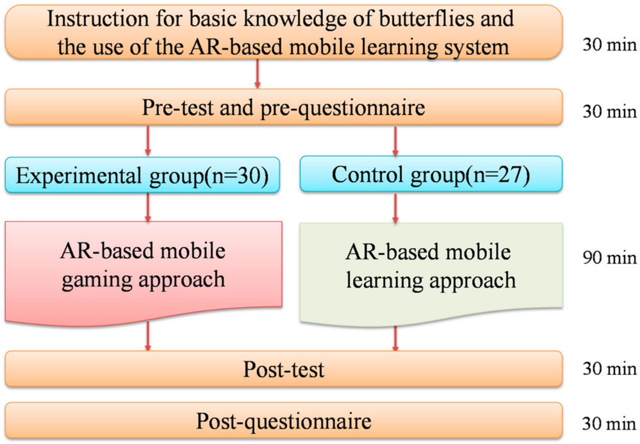

Figure 4. Experiment procedure.

In the second stage, the students in the experimental group were arranged to learn with the AR-based mobile game in the butterfly ecology garden. On the other hand, the students in the control group learned with the AR-based mobile learning system; that is, they were guided by the mobile learning system with AR technology for observing the learning targets (e.g. host plants of butterflies, different growing stages of butterflies and the relationships between the plants and the butterflies) and complete the learning tasks in the butterfly ecology garden. The control group students were also allowed to access the supplementary materials and receive the learning guidance from the system when failing to correctly answer some questions.

The learning activity lasted 90 minutes. After the learning activity, both groups of students took a post-test; moreover, they were asked to fill in the post-questionnaire for measuring any possible change in their attitudes.

Measuring tools

The pretest aimed to evaluate the students' prior knowledge of butterflies. It consisted of 10 yes-or-no items and 10 multiple-choice items, with a total score of 100. The post-test was designed to evaluate the learning achievement of the students, including 10 multiple-choice items, two matching items and four short-answer questions with total scores of 20, 30 and 50, respectively. Both the pretest and the post-test were developed by consulting two teachers who had taught the butterfly ecology course for more than 10 years.

The questionnaire of learning attitudes was modified from the measure developed by Hwang and Chang (2011). It consists of seven items (e.g. "The natural science course is valuable and worth studying" and "I would like to know more about the learning targets") with a five-point Likert scale. Cronbach's alpha value of the questionnaire was .86.

Experimental results

Learning achievement

One of the objectives of this study was to examine the effectiveness of the proposed approach in terms of improving the students' learning achievement. ANCOVA was used

Table 1. Descriptive data and ANCOVA of the post-test results.

Group	*N*	Mean	SD	Adjusted mean	Std. error	*F*
Experimental group	30	51.23	13.25	50.76	1.98	2.24*
Control group	27	43.78	11.53	44.31	2.09	

*$p < .05$.

Table 2. *t*-test result of the students' attitudes toward science learning after the learning activity.

Group	*N*	Mean	SD	*t*
Experimental group	27	4.45	0.60	2.13*
Control group	23	4.06	0.68	

*$p < .05$.

to exclude the difference between the prior knowledge of the two groups by using their pretest scores as the covariate and the post-test scores as the dependent variable. The homogeneity test result showed that the post-test scores of the two groups were homogeneous ($F = 1.99$, $p = .16 > .05$), implying that ANCOVA could be applied. Table 1 summarizes the ANCOVA results, in which the adjusted mean values of the post-test scores were 50.76 for the experimental group, and 44.31 for the control group; moreover, a significant difference was found between the two groups with $F = 2.24$ and $p < .05$, implying that the proposed approach had significantly positive effects on the students' learning achievements.

Learning attitudes

Before the learning activity, the two groups of students took a learning attitude pre-questionnaire. It should be noted that three experimental group students and four control group students did not fill in the questionnaire after the learning activity; therefore, when analyzing the questionnaire ratings, the number of students is 27 for the experimental group and 23 for the control group. The means and SD's of the learning attitude pre-questionnaire ratings were 3.45 and .65 for the experimental group, and 3.51 and .56 for the control group. The *t*-test result showed that no significant difference was found between the pre-questionnaire ratings of the two groups, with $t = -.35$ ($p > .05$).

After the learning activity, the two groups of students took the learning attitude post-questionnaire for evaluating their attitudes towards taking the natural science course after experiencing the learning approaches. Table 2 shows the *t*-test result of the post-questionnaire ratings of the two groups; it is found that the students in the experimental group showed significantly better learning attitudes than those in the control group. This implies that the mobile game approach could improve the students' learning attitudes more than the AR-based mobile learning approach. This finding conforms to several previous studies which reported that the lead-in of gaming strategies might benefit students in terms of improving their learning attitudes as well as their learning achievements (Hwang, Yang, & Wang, 2013; Sung & Hwang, 2013).

Discussion and conclusions

In this study, an AR-based gaming approach for supporting in-field mobile learning activities is proposed. From the experiment conducted in an elementary school natural science course, it is found that the proposed approach is able to promote students' learning attitudes and improve their learning achievements. Such findings are quite different from those reported by Chu (2014) that students might feel frustrated and show disappointing learning achievements when facing complex and rich learning resources from both the real world and the digital world. Moreover, unlike those previous studies that aimed at providing a gaming interface for students to learn via mobile devices (e.g. Sintoris et al., 2010), this study employed a competitive gaming strategy to encourage students to make observations and seek answers on their own and to experience the events presented using the AR technology in the field. The success of employing gaming in educational settings is not obvious. In fact, several previous studies of digital game-based learning have shown that students might regard learning strategies or tasks as interference during game-based learning activities (Charsky & Ressler, 2011; Hwang, Yang, & Wang, 2013). In particular, when paying full attention to the gaming missions, students might treat learning tasks or learning content as an interference that causes an unpleasant experience if the learning materials are not well incorporated into the gaming scenarios. This suggests that, in the proposed approach, the competitive gaming missions can be well integrated with the learning tasks and content (Hwang, Wu, & Chen, 2012).

On the other hand, it should be noted that the QR-code technology is adopted in the present study because it is a highly accepted sensing technology in elementary schools in Taiwan from the aspects of easy-to-implement and low cost; therefore, the proposed approach can be applied to the in-field activities for most of the schools.

To sum up, the main contributions of this study are proposing the AR-based gaming approach for supporting in-field mobile learning activities and showing the effectiveness of the approach via conducting an experiment. In addition to the effectiveness of the proposed approach, one of the major contributions is that the approach can be applied to other fields by substituting the gaming missions and supplementary materials without affecting the enjoy ability of the game. For researchers or teachers who intend to apply the competitive gaming approach to other AR-based in-field activities, a three-step learning design procedure is recommended: (1) Select the activities that require students to explore or make observations in real-world contexts; (2) Prepare a set of questions related to the real-world contexts for the competitive game; and (3) Determine the location and content for each AR-based events.

In the future, it would be worth trying to apply the approach to more courses, such as social studies courses and environmental and ecological courses. It could be interesting to take the personal factors of the learners, such as learning styles and knowledge levels, into consideration when investigating the impacts of the proposed approach. It could also be valuable to analyze and compare the learning patterns of students who learn with the competitive mobile game and the AR-based mobile learning approach. In addition, as the QR-code technology used in this paper is an old and mature method in current AR technology, in future studies, it would be worth trying the markerless tracking technology to offer a more nature interactions in the field trip.

Disclosure statement

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