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# Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment

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ABSTRACT

An antagonistic relationship is traditionally seen as existing between eco-education and technology, with conventional instructional approaches usually characterized by a commentator guiding students in field learning. Unfortunately, in this passive learning approach, the discovery of rich ecological resources in eco-environments to stimulate positive emotions and experiences is often condensed into a "sightseeing". Therefore, precise and systematic guidance focused on providing a rich learning experience is needed in field learning and eco-education. Based on Kolb's experiential learning theory, the current study develops an eco-discovery AR-based learning model (EDALM) which is implemented in an eco-discovery AR-based learning system (EDALS). In a field experiment at a botanical garden, 21 middle school students constitute three groups participated in a learning activity using different learning types and media. Quantitative results indicate that, compared to the human-guidance-only model, EDALS successfully stimulates positive emotions and improved learning outcomes among learners. In post-activity interviews, students indicated they found the exploration mode provided by the proposed system to be more interesting and helpful to their learning in school. The use of attractive technologies increase students' willingness not only to learn more about the environment, but also to develop a more positive emotional attachment to it.



## 1. Introduction

Modern economic and human development trends has increasingly created a polluted environment, thus highlighting the urgent need for ecological education. While many Asian countries stress ecological education, they perform poorly in instituting affective education (Chang, Chen, & Hsu, 2011; Gurevitz, 2000) and elementary and middle school ecological and environmental education is still carried out in classroom. This lack of real-world interactions and exploration makes it difficult for students to develop an emotional attachment for or interest in ecology, thus limiting their enthusiasm for practicing environmental protection (Hautecoeur, 2002). In addition, numerous studies of human interaction with real ecological environments have found that "emotion" is an important learning factor, but is frequently overlooked. Reis and

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Roth (2009) pointed out the importance of emotion in ecological environment education, and the problems that can arise when such emotion is lacking.

Botanical gardens help maintain plant diversity in urban areas and provide opportunities for learners to experience complex ecosystems. Rich ecological and learning resources make botanical gardens a suitable outdoor informal learning environment (Chang et al., 2014; Chiou, Tseng, Hwang, & Heller, 2010; Liu, Lin, Tsai, & Paas, 2012). However, traditional display cards at such gardens typically only render information via text or graphics, often providing only a very limited introduction to specific plants. This approach makes it provide the rich information learners need to truly explore their environment, and limits the learning effectiveness of outdoor teaching (Sommerauer & Müller, 2014). Although audio tours have become quite common in recent years, and provide users with more in-depth explanations than conventional signage, such systems still cannot provide systematic and interactive learning in outdoor learning environment (Chang et al., 2014). Theoretically, assistive technology that can provide learners with expanded access to practical real-world information could provide a more effective approach to implementing ecological educational activities in contexts such as botanical gardens.

The development of information technologies has led to many innovations in modern teaching and learning methods. Integrating new technologies into instruction allows teachers to transform learning materials from a fixed combination of texts and graphics into more interactive multimedia material. The integration of digital learning with convenient and fast internet technology has further lowered the barrier of differentiated teaching and helped to overcome time and space constraints in traditional teaching models, thereby moving students from the passive reception of knowledge to more active learning approaches (Liu et al., 2012; Mohammadyari & Singh, 2015). Smart phones and tablet computers have recently emerged as mainstream devices for use in mobile learning. Harris (2001) believed that the convenience and immediacy of mobile learning provides more learners with additional learning opportunities. Mobile learning allows teaching/learning to be carried out in authentic outdoor learning environments, providing learners with a broader range of opportunities to acquire knowledge. Moreover, authentic learning environments do more to evoke affective feeling than classroom learning environments (Gulikers, Bastiaens, & Martens, 2005; Sommerauer & Müller, 2014).

Given the limitations of real world education in ecological environments and regular disregard for emotion factors, this study uses botanical garden-based outdoor ecological learning as an experimental situation, integrating experiential learning theory to strengthen real-world exploration, and adopts augmented reality (AR) technology to create an mobile learning system to break through real-world information limitations, thereby exploring learning effectiveness and learners' emotional conversion process.

The present work designs and implements a coordinated actual and AR virtual action ecological learning system based on experiential learning theory. Furthermore, an AR system is developed to apply the experiential learning model to ecological education. In addition, this study examines the impact of learner emotion on experiential learning and learning performance using the AR action ecological learning system.

## 2. Literature review

### 2.1. Augmented reality in education

Milgram and Kishino proposed that the actual and virtual environment are on a continuum (Milgram's Reality-Virtuality Continuum, Fig. 1) and defined AR as a sort of display device that allows for the visualization of virtual objects in a real world environment. AR can be defined as any case in which an otherwise real environment is "augmented" by means of virtual objects (Milgram, Takemura, Utsumi, & Kishino, 1994). This technology allows users to interact with virtual images in real world contexts (Chen & Tsai, 2012). AR layers computer-generated sensory inputs such as audio, video, graphics or GPS data on a live direct or indirect view of a physical real-world environment (Wu, Lee, Chang, & Liang, 2013). Therefore, AR can provide image transfer information, using electronic devices to allow users to experience the integration of the real and virtual environments (Klopfer & Sheldon, 2010). Moreover, the use of visual interaction and operation can enhance the user experience (Dunleavy, Dede, & Mitchell, 2009). With the help of advanced AR technology, observers can digitize information in the surrounding real world and make them operable.

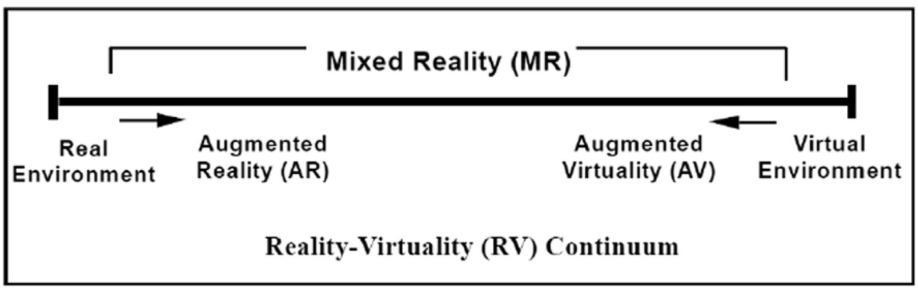


**Fig. 1.** Milgram continuum (Milgram et al., 1994).

AR technology can provide new opportunities to promote learning and establish constructive learning environments. Previous studies have established that the educational value of AR has increased significantly in recent years, and is considered by some to be a likely candidate to emerge as a significant pedagogical tool for improving learning outcomes (Dede, 2009). Past studies on AR focused largely on technology development and practical implications in different learning environments (Cheng & Tsai, 2014; El Sayed et al., 2011; Wei, Weng, Liu, & Wang, 2015; Zhou, Duh, & Billinghurst, 2008). At the same time, some scholars called for additional research for the potential role of AR in education. In the past 5 years, the rapid development of smart mobile devices has raised the potential for AR to move from the experimental development stage to deployment as a ubiquitous learning tool.

In 2010, Johnson et al. proposed AR technology as a key educational technology for the next five years (Johnson, Levine, Smith, & Haywood, 2010). Other studies emphasized five potential AR applications in education: (1) Learning 3D object recognition and observation (Chen, Chi, Hung, & Kang, 2011; Kerwalla et al., 2006). (2) Combining wireless Internet and location detection technology to build ubiquitous learning (Broll et al., 2008; Dunleavy et al., 2009). (3) Providing learners with presence, immediacy and immersion (Squire & Jan 2007). (4) Visualizing abstract concepts (Arvanitis et al., 2007; Dunleavy et al., 2009). (5) The convergence of formal and informal learning (Sotiriou & Bogner, 2008). Regardless of which specific technology was proposed for use in developing learning activities, all these studies are consistent in that they claim that AR-enabled learning environments can enhance learning motivation and effectiveness. Faced with the increasing importance of ecological education, this study uses AR technology to build an action ecological learning system, allowing learners to access richer and more lively learning information in authentic environments without disturbing the surrounding ecology; the proposed system entails no additional cost on hardware, so as to enhance the effectiveness of experiential learning.

### 2.2. Kolb's experiential learning theory

"Experience" is an activity, and it is also a result of activity. In terms of being an activity, experience refers to the processes by which people create and reflect on personal experience. As a result of activity, experience means voluntarily participation in various activities (Clark, Threeton, & Ewing, 2010) through which people are able to apply knowledge and insights gained during the process to daily life and future life. Experiential learning differs from teacher-centered didactic instruction in that it emphasizes independent judgment, free thinking, and personal experience. Through interactive learning processes, students gain personal experience from which they derive an understanding of the core elements of learning tasks and explore the relation between activity concepts and implications. Learners convert the experience gained through the learning activity into an integral part of their lives, thus transforming their attitudes and prompting further reflection on extrinsic behaviors.

Kolb first proposed experiential learning (1984), arguing that learning is a process of experience conversion (Dunlap, Dobrovolny, & Young, 2008). The experiential learning cycle includes four cyclical learning stages: (1) concrete experience, (2) observation and reflection, (3) forming abstract concepts and generalizations, and (4) testing in new situations. Learners must go through this cycle to complete the learning experience. The four stages are continuous and experience occurs at any time. Each experience will affect the formation of future experiences.

Experiential learning theory emphasizes the correlation between concrete experience and learning, which matches the ostensive purpose of establishing botanical gardens. However disorganized and unsystematic visits to such facilities result in low learning effectiveness. Accordingly, this study seeks to integrate experiential learning into the visiting process and system design, thereby strengthening the effectiveness of experiential learning.

### 2.3. Emotion and experiential learning

Previous studies have differentiated the three similar concepts of emotion, affection, and mood. With respect to the short duration of mood, affection refers to a long-term and general state of mind, including psychological processes of affection, emotion and temperament (Snow, Corno, & Jackson, 1996). Emotion refers to a stable emotional reaction generated in a specific place, situation and field. Emotion comes from the individual's subjective awareness; such awareness is often mixed with psychological and physiological states that are generated by a variety of feelings, thinking, and behaviors (Plutchik & Kellerman, 1986, 2003). From a psychological point of view, emotion is classified into positive and negative emotions. Positive emotions are often interpreted as joyful and happy while negative emotions are described as angry and anxious. Previous studies hold quite diverse views on the types and architecture of emotion (Fisher, 2005; Fredrickson, 1998, 2001; Seligman, 2002; Spector, 2002). Similarly, many psychologists have promoted the emotional impact of individual learning behavior and psychological and physiological feedback (Pekrun, Elliot, & Maier, 2006; Pekrun & Frese, 1992). Baron et al. (1996) defined the characteristics of positive emotion as a tendency towards ease and comfort, indicating that when people experience positive emotion, they are more likely to view surrounding people and things with a pleasant state of mind. Thus, positive emotion is held to contribute to learning while negative emotion may suppress learning (Pekrun, 2000).

Based on previous findings (Fredrickson, 1998, 2001, 2003; Jusge et al., 1999; Seligman, 2002), the present study categorizes learning emotions as positive (quiet, pleasant, happy, confident, positive, and hopeful) and negative (bored, anxious, depressed, tense, angry, and enraged). A mobile-device-based system is devised to record learning emotions in real-time to provide insight into learners' emotional processes in authentic ecological educational environments.

## 3. Research design

### 3.1. Eco-discovery AR-based experiential learning model

The beneficial effect of authentic outdoor environment on ecological learning outcomes is often limited by the lack of on-site information. Therefore, to allow students to become immersed in environmental exploration and interaction with AR-enhanced ecological information in a botanical garden setting, this study developed an innovative learning model, the eco-discovery AR-based learning model (EDALM) (Fig. 2). EDALM integrates AR technology with the four stages of Kolb's experiential learning cycle (Kolb, 1984): concrete experience, reflective observation, abstract conceptualization, and active experimentation. Furthermore, AR technology and mobile devices are coupled to build an eco-discovery AR-based learning system (EDALS). The system plays two roles in experiential activities: (1) it helps learners navigate the learning area in the garden and prevents learners from getting lost in exploring botanical gardens; and (2) the AR system integrates virtual information into the actual environment to enrich the educational meaning of the real ecological environment and to strengthen the impact of exploratory learning.

### 3.2. Design of experiential activity

To understand the impact of the system on emotion and learning effect in the ecological education context, this study conducts three post-activity assessments, and conducted a whole day learning experiment at the National Museum of Natural Science-Botanical Garden, Taichung, Taiwan. The subjects were 21 middle school students randomly assigned to three groups (7 in each group) with approximately equal numbers of boys and girls in each group. The three groups were: (1) Group A used the AR system for self-learning; (2) Group B used AR plus commentator, where learning is accomplished via AR system instruction and commentator guidance; and (3) Group C was a control group using traditional experiential learning, in which students followed the commentator through the gardens and listened to commentator guidance (Table 1).

To avoid interference from situational factors, all three groups followed an identical learning route in the garden: 1. Taitung Cycads → 2. Monsoon Rain Forest → 3. Central Lowlands → 4. Tropical Rainforest Greenhouse (Fig. 3). The groups all toured the garden on the same day, but with staggered starting times to ensure no overlap.

Specific experimental procedures involved the three groups first taking an indoor 15-min paper-based pre-test to assess their basic knowledge of and emotional attachment to plants. All participants were required to complete a series of experiential tasks, including indicating their pre-task emotional state, completing the learning tasks, indicating their post-task emotional state, and answering questions. Group C finished all tasks using pencil and paper (without EDALM), while each member of groups A and B were provided with a tablet computer with which to use EDALM. To ensure system familiarity, groups A and B received additional guidance on EDALS on their tablets before entering the garden. After indicating their pre-

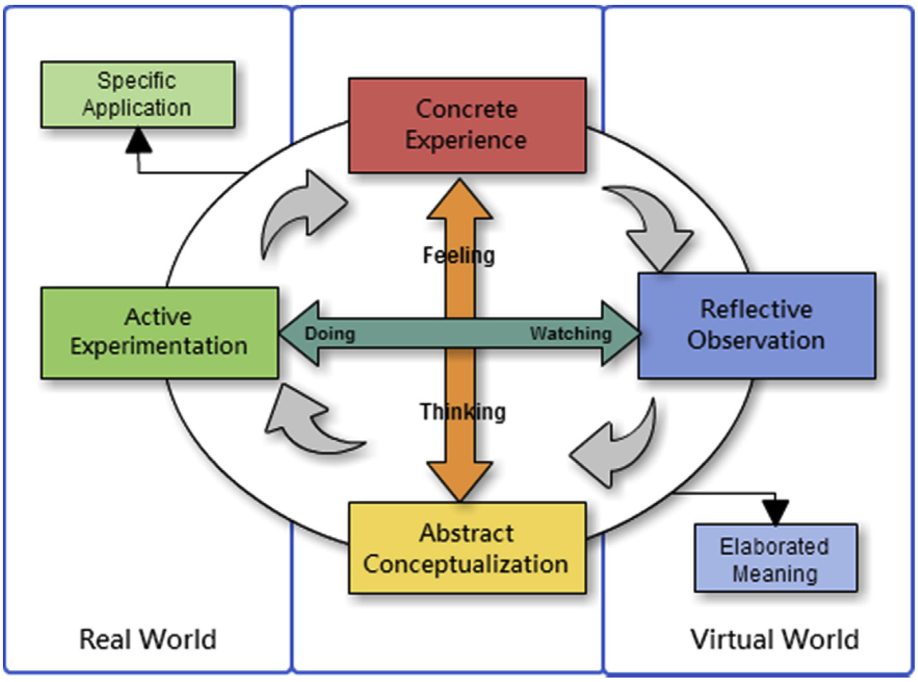


**Fig. 2.** Eco-discovery AR-based learning model (EDALM).

**Table 1**
Conditions of subjects assigned to each group.

| Group | Learning pattern | Learning tools | Interpretation tour |
|---|---|---|---|
| Group A: AR group<br>AR learning group | AR experiential learning | EDALS | N/A |
| Group B: AR plus commentator<br>AR and interpreter guiding group | AR experiential learning | EDALS | Yes |
| Group C<br>Control group | Traditional experiential learning | Paper handouts | Yes |

task feelings, they read learning themes related to the eco-area. The AR feature in the operation system presents an interactive virtual plant silhouette (Fig. 4) and subjects were prompted to learn about related plants (Fig. 5), guiding them to experience and explore the surrounding environment. Fig. 6 shows experimental situations for the three groups.

Subjects were then prompted to indicate their post-task emotions, and answer 4 to 6 achievement assessment questions to complete the learning theme before moving on to the next theme. After all four learning themes are complete, the subjects were asked to complete a questionnaire on the experiential learning activity. Six subjects were randomly selected for interviews to learn more about their learning conditions using the AR system and the emotions raised by the experience.

### *3.3. Experimental tools*

The data obtained from the "emotion self-assessment questionnaire" and "experiential activity questionnaire" were quantitatively analyzed to assess the impact of different learning tools on feelings, activity performance and learning effectiveness.

The experiential activity questionnaire was adapted from the activity assessment tool used in a study by Abdullah (2014). After translation and editing, the scale of experiential activity was divided into engagement, challenge, interest, and competency. The whole scale contains a total of 13 questions, 10 quantified questions using a five-point Likert scale, and 3 open questions.

The emotion self-assessment questionnaire asks participants to select adjectives describing positive and negative emotions, and was adapted from previous studies. After collation and analysis, the questionnaire contained 6 positive emotional adjectives and 6 negative emotional adjectives. The questionnaire is interpreted based on emotional expressions and degree of emotion (Fredrickson, 2003; Seligman, 2002; Spector, 2002). The questionnaire was pre-tested with 20 graduate students, and then divided into two phases. In the first phase, emotional expression is combined with emotional adjectives, with each expression corresponding to an adjective. In the second phase, positive and negative emotions are assigned scores. To quantify the learning emotions of each student, emotions are assigned with points from most negative (1) to most positive (12).

Additionally, in order to have deep understanding of learners' feedback about learning experience, this study adopts an open-ended interview survey to collect qualitative data by one interviewer. Sample questions of the interview are "what do you think about the AR system?", "what's the differences between the experience of this time and before?", "is the activity helpful to your biology academic performance?". The question design is based on the orientations in the experiential activity questionnaire. Six respondents were randomly selected from three groups (i.e. two respondents were selected from each group) after conducting quantitative questionnaires. The interviews were recorded by a sound recorder and did not press each learner for a direct answer. Those data were presented in the format of verbatim texts. The implications of interview results are integrated in the discussion section.

## 4. Results

In this study, the goal is to explore the impact of different learning tools and different experiential approaches on learners' emotional affection and learning effectiveness in an ecological experiential learning environment. A pre-test and post-test design was used to examine the impact of learning tools based on the post-test emotional affect and learning effectiveness.

### *4.1. Pretest-prior achievement, prior knowledge*

After being randomly assigned to three groups, all participants were given a pre-test to ensure the homogeneity of the pre-activity state. Since there are only 7 participants in each experimental group, this study applied the Kruskal-Wallis test to each student's school grades for a unit on plant ecology from the most recent semester and administered a prior knowledge quiz to assess the difference between participants' in-school learning achievement and prior knowledge. Then, a Dunn multiple comparison test was used to run multiple comparisons of averages of the three groups. The results showed no significant difference between in-school learning achievement ($\chi^2 = 2.70$, $P > 0.05$) and prior knowledge ($\chi^2 = 0.052$, $P > 0.05$) for the three groups, meaning the performance of participants of the three groups is homogeneous (Table 2).

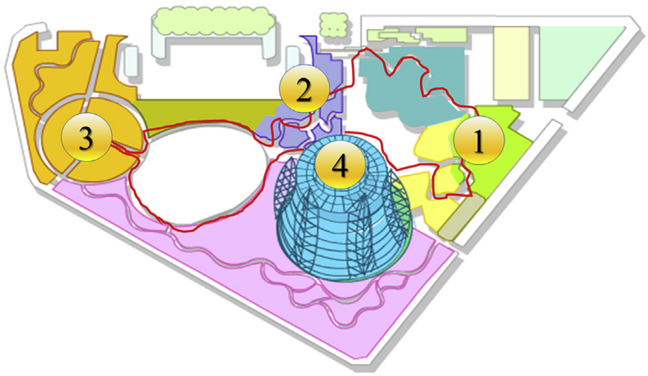


**Fig. 3.** Four subject areas and learning route in the botanical garden.

### 4.2. Learning outcomes

The difference in terms of learning effectiveness for the three groups reaches a level of statistical significance ($p < 0.05$). The Dunn multiple comparison test shows that, among the three groups, the AR plus Commentator Group has better learning effectiveness than the control group, and that these two groups have similar pre-activity emotional affect, but that the post-activity emotional affect of the control group is 7.96 as opposed to 9.71 for the AR plus Commentator group, achieving a level of significance (, $P < 0.05$), as shown in Table 3.

### 4.3. Learning emotions during the experiment

Table 4 shows the result of the Kruskal-Wallis test for pre- and post-activity emotions. The results show no significant difference in terms of pre-learning emotion (, $P > .05$) between the three groups, but a significant difference in terms of post-learning emotion (, $P < 0.05$), with students who used the AR learning system tending to have more positive post-activity emotions. The Dunn multiple comparison test results for post-activity emotion shows that the AR plus Commentator group (group B) had the most positive affect.

### 4.4. Experiential learning activity

Table 5 summarizes the descriptive statistics for the experiential activity questionnaire. Engagement (ENG), Competency (CMP), and Interest (INT) all show significant levels of difference, while Challenge (CHA) does not ($p > 0.05$).

The study further uses nonparametric Dunn multiple comparison test (Table 6) to find that in Engagement (ENG) scale, the difference between Control Group and AR plus Commentator Group is significant ($p < 0.05$); in Competency (CMP) scale, the difference between Control Group and AR Group is significant ($p < 0.05$); and in Interest (INT) scale, the difference between the three groups is not significant.

## 5. Discussion

### 5.1. Tech-and-human model is the most effectiveness for ecological learning

The AR plus Commentator Group (Group B) exhibited the best learning performance. One student commented, *"(I) feel that participating in activities makes me perform better in biological quizzes."* The integrated learning model imposes no additional cognitive burden for students, but rather produces a complementary effect. The friendly guidance of staff helped compensate for potential alienation resulting from use of unfamiliar technologies, while the personalized technology overcomes problems posed by lack of human resources (Peiqiong, 2011; Saariluoma & Jokinen, 2015; Shao-hua, 2012).

One student noted *"It is good that we can immediately see the test results."* This highlights that students value immediate feedback to clarify concepts and that such feedback encourages further learning. In contrast, during the learning process, students in Group C (i.e., commentator only) were compelled to search, observe, memorize and understand plant-related information with only limited information. Students in Group A who relied on the proposed system alone for guidance were grouped together, but learned in isolation. Although the technology enables information transmission, interpersonal interaction and support is still crucial to increasing learner engagement (Huang, Huang, & Yu, 2011).


**Fig. 4.** Screen shot of an interactive virtual plant silhouette.

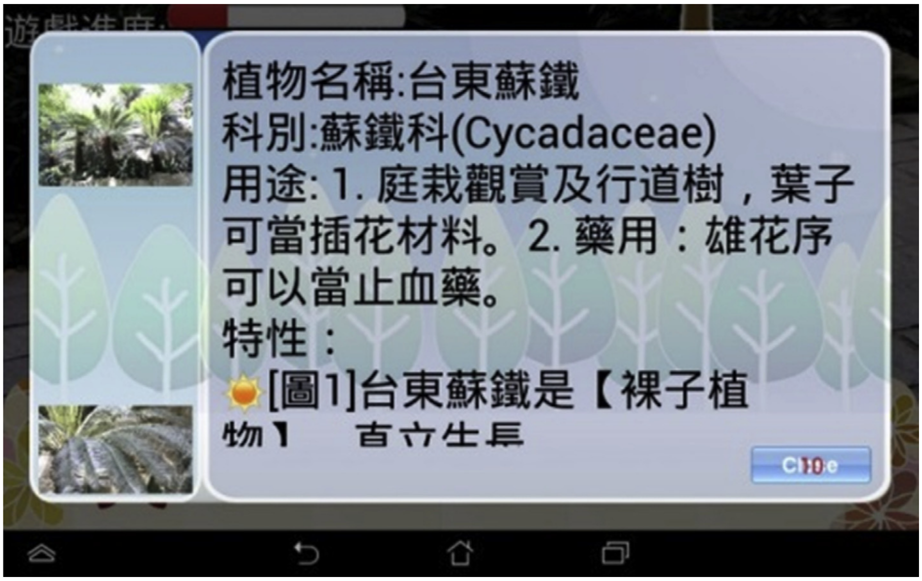


**Fig. 5.** Learning content about specific plants.

### *5.2. Impact of system design with anthropomorphisms and AR features on positive emotion and ecological experiential experience*

The proposed AR action ecological learning system allows real spaces to be integrated with anthropomorphic learning scenarios, thereby enhancing students' learning experience and positive emotions. The literature on anthropomorphisms in multimedia learning content appears to be generally compatible with the more detailed results obtained in the present study (Park, Flowerday, et al., 2015, Park, Knörzer, et al., 2015). However, the current study enhances previous findings by providing a much more detailed examination of emotional measures. The results show that there is a slight difference in terms of experience and positive emotions between the AR Group (Group A) and the AR plus Commentator Group (Group B), but the difference is not statistically significant. However, the difference in comparison to the Control Group is statistically significant, highlighting the impact of the AR system on enhancing experience and emotions. The competency aspect of ecological experiential learning refers to the learner's subjective assessment of newfound ability and sense of accomplishment following learning. This raises the question: why do students still feel a sense of competency when they are assisted systematically? Our


**Fig. 6.** Situations in the experimental field.

**Table 2**
The results of Kruskal-Wallis test on in-school learning achievement of Group A, B, and C.

| | N | Mean | | Chi-square | | *df* | | Sig | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ach. | Pri-K | Ach. | Pri-K | Ach. | Pri-K | Ach. | Pri-K |
| AR group (Group A) | 7 | 14.00 | 42.86 | 2.70 | 0.052 | 2 | 2 | 0.259 | 0.974 |
| AR plus commentator (Group B) | 7 | 10.29 | 41.14 | | | | | | |
| Control group (Group C) | 7 | 8.71 | 40.29 | | | | | | |

$^{*}p < 0.05$.

**Table 3**
Results of Kruskal-Wallis test and Dunn multiple comparison test for learning effectiveness.

| | | N | Grade average | Average | Chi-square | Significance | |
|---|---|---|---|---|---|---|---|
| Learning effectiveness | AR Group (Group A) | 7 | 11.71 | 67.08 | 6.602 | 0.037* | 0.333 (A)>(C) |
| | AR + Commentator (Group B) | 7 | 14.86 | 72.96 | | | 0.033* (B)>(C) |
| | Control Group (Group C) | 7 | 6.43 | 57.00 | | | 1.000 (B)>(A) |

$^{*}p < 0.05$.

**Table 4**
Kruskal-Wallis pre-learning and post-learning results.

| | Mean | | | Chi-square | Significance | Dunn test |
|---|---|---|---|---|---|---|
| | AR group (Group A) | AR + commentator (Group B) | Control (Group C) | | | |
| Pre-test | 13.00 | 13.43 | 6.57 | 5.549 | 0.062 | |
| Post-test | 12.07 | 14.93 | 6.00 | 7.665 | 0.022* | (B)>(C) 0.020* |

$^{*}p < 0.05$.

findings suggest that traditional guided-tour approach leaves learners reliant on the commentator's knowledge. By establishing a virtual environment for personal exploration, the present study empowers students to explore and study on their own, giving them a greater sense of competency. In terms of interest, students in Groups (A & B) who used the AR system said *"(I) would like to use the system again,"* *"(I) will participate the event again if there is an opportunity to do so,"* and *"(It) is helpful*

**Table 5**
Summary descriptive statistics and results of Kruskal-Wallis test.

| Orientation | Items | AR group (A) | AR + commentator (B) | Control group (C) | Average | Standard deviation |
|---|---|---|---|---|---|---|
| ENG | The botanical garden outdoor course made me feel happy. | 4.4 | 4.7 | 3.9 | 4.33 | 0.66 |
| | The botanical garden outdoor activity is interesting. | 4.4 | 4.7 | 3.7 | 4.29 | 0.71 |
| | I enjoyed the botanical garden outdoor activity. | 4.4 | 4.4 | 3.9 | 4.24 | 0.70 |
| | | Grade average | | | Chi-square | Sig |
| | | 12.71 | 14.29 | 6.00 | 7.500 | 0.024* |
| CMP | I learned how to identify plants in this botanical garden activity. | 4.4 | 4.1 | 3.3 | 3.95 | 0.74 |
| | I felt a sense of accomplishment upon completion of the botanical garden activity. | 4.4 | 4.1 | 3.6 | 4.05 | 0.86 |
| | Participation in this activity enhanced my learning skills in nature and life science. | 4.3 | 4.3 | 3.7 | 4.10 | 0.77 |
| | | Grade average | | | Chi-square | Sig |
| | | 14.14 | 12.57 | 6.29 | 6.492 | 0.039* |
| CHA | I think the problems in botanical garden activity are difficult. | 3.0 | 2.7 | 3.1 | 2.95 | 1.32 |
| | The botanical garden activity is challenging. | 2.0 | 1.9 | 2.6 | 2.14 | 0.85 |
| | | Grade average | | | Chi-square | Sig |
| | | 10.64 | 9.21 | 13.14 | 1.514 | 0.469 |
| INT | Participation of this activity enhanced my curiosity and interest in nature and life science courses. | 4.3 | 4.1 | 3.4 | 3.95 | 0.74 |
| | Participation in this activity gave me a stronger understanding of plants/animals. | 4.4 | 4.4 | 3.7 | 4.19 | 0.60 |
| | | Grade average | | | Chi-square | Sig |
| | | 13.50 | 13.07 | 6.43 | 6.338 | 0.042* |

*$p < 0.05$.

*for academic performance. (It makes me) want to learn biology. My biology score is low and (after the activity) I would like to read the textbook more."* In contrast, students in Group C, who had the opportunity to use the system only after the experiment was completed, said that *"It is boring in the beginning (when the system is unavailable)."* This suggests that the AR system enhances students' sense of fun in exploratory learning and aroused their curiosity.

In terms of emotional affect, the AR plus Commentator Group (Group B) shows the most positive outcome. Students in this group noted that *"The tablet increases the fun; it is more interesting and it's easier (for me) to concentrate," "I felt bored when I visited this place before; it is fun this time with the tablet," "It is fun to explore the plants with my classmates."* This shows that the virtual—actual interaction created by the AR system triggers learner interest and learners derive more pleasure from learning. Despite having the greatest opportunity to strengthen positive emotion via interpersonal interaction, students in the Control Group (Group C) exhibited less positive emotion than students in the other two groups. In a one-to-many context, this mode of instruction cannot meet the learning/engagement needs of individual students. The presentation lacks of variety, making it difficult to enhance positive emotion (we refer to this situation as a "monotonous emotional trap"). However, different instructional approaches are likely not the only reason for the different emotional outcomes as evidenced by individual differences in subjective level of situational interest, a phenomenon that can foster learning given sufficient cognitive resources in the learning situation (Park, Flowerday, et al., 2015). Therefore, the establishment of a mediator or moderator role to foster situational interest between instructional approaches and learning emotions should be further investigated.

## 6. Conclusions

Experimental results and student feedback suggests that, although students in Taiwan are largely familiar with tablet computers, they are not accustomed to using digital products in outdoor environments for learning purposes. Due to the high cost of such equipment, the difficulty of requiring all learners to prepare devices with similar specifications, or parental resistance to the use of such products in learning, few students have actually used tablet computers for personalized learning in formal educational contexts. This study hopes that validation of the efficacy of the proposed system could prompt new attempts to find appropriate applications for such technology in education. Future work will apply the developed system and teaching model to more diverse themes, expand system usage to a wider range of ages, and promote the concept of integrating AR into experiential learning.

The current study suffers from some limitations which may limit the generalizability of our findings. First, the learning content is only relevant for 7th graders and the findings cannot be generalized to other populations. Moreover, due to time and logistical restrictions, the experimental duration is limited to a single day, and a longitudinal follow-up study could more deeply explore interaction between learner emotion and the learning environment (Goleman, 2001).

**Table 6**
Result of Dunn multiple comparison test on different orientations of experiential activity of the three groups.

| Orientation | Sample1–Sample2 | Significance after adjustment |
|---|---|---|
| Engagement (ENG) | Control group–AR group | 0.097 |
| | Control group–AR plus commentator group | 0.033* |
| | AR group–AR plus commentator group | 1.000 |
| Competency (CMP) | Control group–AR plus commentator group | 0.162 |
| | Control group–AR group | 0.048* |
| | AR plus commentator group–AR group | 1.000 |
| Interest (INT) | Control group–AR plus commentator group | 0.105 |
| | Control group–AR group | 0.074 |
| | AR plus commentator group–AR group | 1.000 |

*$p < 0.05$.

This study focuses on the emotional impact of integrating AR technology into learning. Future work can focus on the intermediary effect of different emotional capacities in a single environment and also on the possibility of using AR technology to combine sensing devices to enhance emotional competence. Furthermore, learners' emotional states should be considered in experiential learning research. Together with the results of previous studies (Park, Flowerday, et al., 2015, Park, Knörzer, et al., 2015; Plass, Heidig, Hayward, Homer, & Um, 2014) research on emotional design is needed to integrate affective and cognitive processes. By applying theoretical models, such as the *Integrated Cognitive Affective Model of Learning with Multimedia* (ICALM) (Plass & Kaplan, 2015), we intend to continue pursuing this line of investigation in a series of experimental studies.

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