An Augmented Reality-based Mobile Learning System to Improve Students’ Learning Achievements and Motivations in Natural Science Inquiry Activities

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ABSTRACT

In this study, an augmented reality-based mobile learning system is proposed for conducting inquiry-based learning activities. An experiment has been conducted to examine the effectiveness of the proposed approach in terms of learning achievements and motivations. The subjects were 57 fourth graders from two classes taught by the same teacher in an elementary school in northern Taiwan. The experimental results showed that the proposed approach is able to improve the students’ learning achievements. Moreover, it was found that the students who learned with the augmented reality-based mobile learning approach showed significantly higher motivations in the attention, confidence, and relevance dimensions than those who learned with the conventional inquiry-based mobile learning approach.

Keywords

Teaching/Learning strategies, Elementary education, Cooperative/Collaborative learning, Interactive learning environments

Introduction

Recently, the advancement and popularity of handheld devices and sensing technologies has enabled researchers to implement more effective learning methods (Ogata, Li, Hou, Uosaki, El-Bishouty, & Yano, 2011). Several studies have reported the importance of conducting contextual learning and experiential learning in real-world environments, encouraging the use of mobile and sensing technologies in outdoor learning activities (Chu, Hwang, Tsai, & Tseng, 2010; Hung, Hwang, Lin, Wu, & Su, 2013; Yang, 2006). For example, Chu, Hwang, Huang, and Wu (2008) developed a learning system that guided students to learn about the characteristics and life cycle of plants on a school campus using mobile communication and RFID (Radio Frequency Identification).

Most of mobile learning studies emphasize the adoption of digital learning aids in real-life scenarios (Sharples, Milrad, Arnedillo-Sánchez, & Vavoula, 2009; Ogata & Yano, 2004; Wong & Looi, 2011). However, regarding supplementary mobile learning aids, the interaction between digital learning aids and the actual environment needs to be emphasized to enable students to effectively manage and incorporate personal knowledge (Wu, Lee, Chang, & Liang, 2013). For example, it is expiated that students can select a virtual learning object from the actual environment using a mobile learning aid, which allows them to obtain a first-hand understanding of the learning environment and, subsequently, increases their learning motivations and experiences. Such a learning support technology is achievable through the use of Augmented Reality (AR), which combines human senses (e.g., sight, sound, and touch) with virtual objects to facilitate real-world environment interactions for users to achieve an authentic perception of the environment (Azuma, 1997). For example, users who employ mobile devices with AR facilities to seek a target building on a street are able to see additional information surrounding individual buildings when they browse the buildings via the camera of their mobile device. Researchers have documented the potential of employing such facilities to assist students in learning in real-world environments in comparisons with traditional instructions (Andujar, Mejias, & Marquez, 2011; Chen, Chi, Hung, & Kang, 2011; Kamarainen, Metcalf, Grotzer, Browne, Mazzuca, Tutwiler, & Dede, 2013; Platonov, Heibel, Meier, & Grollmann, 2006), which showed that AR technology contributed to improve academic achievement compared to traditional teaching methods.

On the other hand, numerous educators have contended that computer technology cannot support the learning process entirely; instead, the primary function of computer technology involves a knowledge building tool for students (Jonassen, Carr, & Yueh, 1998). Effective learning strategies remain the most crucial factor for increasing...
learning motivation. Therefore, effective learning strategies supplemented with appropriate computer technology can greatly enhance learning motivation (Chu, Hwang, & Tsai, 2010; Jonassen, 1999; Hwang, Tsai, Chu, Kinshuk, & Chen, 2012; Jonassen et al., 1998). Previous studies have highlighted that inquiry-based learning strategies supplemented by computer technology in a scenario-based learning environment can effectively increase learning motivation (Shih, Chuang, & Hwang, 2010; Soloway & Wallace, 1997). Inquiry-based learning strategies are student-centric knowledge exploration activities; the teacher serves as a guide, employing structured methods that train and encourage students to learn proactively (Hwang, Wu, Zhuang, & Huang, 2013; Soloway & Wallace, 1997). When students acquire the methods for problem-solving, they use the obtained information to establish a hypothesis or to plan solutions to the problem (Looi, 1998).

Consequently, in this study, an innovative learning approach is proposed to support inquiry-based learning activities with mobile AR. During the activities, the learning system guides the students to complete their learning tasks and provides learning supports by sensing their locations. Through the mobile AR technology, the learning system is able to present differing learning contents on the handheld devices based on individual students’ learning scenarios, such that the students can interact with the learning content to gain relevant knowledge (Yang & Chen, 2008). Finally, the entire learning process is recorded and uploaded, allowing students to share their experiences and perceptions with their peers.

To evaluate the effectiveness of the proposed approach, the following research questions are investigated:

- Do the students who learn with the inquiry-based mobile AR approach have better learning achievements than those who learn with the conventional inquiry-based mobile learning approach?
- Do the students who learn with the inquiry-based mobile AR approach reveal higher learning motivations than those who learn with the conventional inquiry-based mobile learning approach?
- Is there a significant difference between the cognitive loads of the students who learn with the inquiry-based mobile AR approach and the conventional inquiry-based mobile learning approach?

Literature review

Inquiry-based Learning

Inquiry-based learning is a learning activity that involves the teacher encouraging students to proactively hypothesize, explore, validate, categorize, explain, and discuss everyday situations or problems encountered. Through hypothesizing, exploring, and observing, students develop advanced social interaction skills and a higher level of thinking. Inquiry-based learning enables students to not only develop a deeper level of thinking when encountering learning situations but also to learn how to implement the process of learning (Price, 2001). Lim (2004) contended that during the process of conducting learning tasks, online inquiry-based learning allows students to develop confidence to participate in activities, cultivate teamwork abilities, and feel greater responsibility for controlling their learning progress. Creedy, Horsfall and Hand (1992) asserted that traditional learning methods are merely knowledge transfer activities, that is, instructors transfer their knowledge to students, whereas inquiry-based learning allows students to learn proactively rather than passively receiving knowledge. Colburn (2000) defined inquiry-based learning as a method that comprises many open, student-centered, and hands-on approaches, including structured inquiry, guided inquiry, open inquiry, and the learning cycle. These approaches enable students to identify connections on various levels and to integrate and collate information. The instructor then provides the students with relevant concepts, and after this knowledge is assimilated, students are able to apply it in other contexts.

The traditional approach informal education has been criticized for creating artificial classroom contexts where the learning activities and resources become divorced from their meaning in real-life situations (Herrington, Reeves, & Oliver, 2010). The advocates of authentic learning argue for the creation of more meaningful learning situations. Authentic learning requires that the contexts used for learning reflect real-world contexts where the skills and competencies will be deployed. Mayer (2001) also emphasizes the learners’ learning outcomes in integrated text and the illustrator will better than divorced. These AR-based inquiry scenarios can cover a wide range of domains from observation and interaction through to accessing real scientific instruments over the Web to conduct more realistic experiments.

Edelson, Gordin and Pea (1999) attested that the inquiry experience is beneficial for students to correct their
scientific knowledge. In recent years, inquiry-based learning has been broadly applied in nursing education (Akinsanya & Williams, 2004; Finn, Fensom, & Chesse-Smyth, 2010). Inquiry-based learning is also applied in the social sciences (Ahmed & Parsons, 2013; Bowman, 2012). Lakkala, Lallimo, and Hakkarainen (2005) combined history classes with inquiry-based theory for implementation in 12 elementary and junior high schools. Shih et al. (2010) integrated inquiry-based theory with mobile devices to assist students in understanding the culture associated with temples. Chang, Wu and Hsu (2013) also combines mobile AR technology and pedagogical inquiry activities in a socioscientific issue's context is effective in terms of promoting students' understanding of the science content for ninth-grade students.

Augmented reality

AR is a technology that allows users to combine real-life sensory experience with digital environment perceptions (Azuma, 1997). According to Azuma, Baillot, Behringer, Feiner, Julier and MacIntyre (2001), the three characteristics of AR are (a) real and virtual objects incorporated into reality; (b) collaboration between real and virtual objects, and (c) real-time interaction between real and virtual objects.

Display and positioning technologies fulfill the three criteria of AR; differing sensory input is received through environmental changes and, subsequently, the interaction and changes between senses and scenarios are adjusted. Sherman and Craig (2003) further explained that the presentation of sensory characteristics is only achievable through the level of environmental reality and activity immersion; therefore, differing levels of sensory experience can be achieved through different display and positioning technologies. Furthermore, if the augmented information of the real object is comprehensive, the sensory experience and knowledge transmission will be accurate; conversely, if the augmented information is incomplete, the sensory input and knowledge transfer will be inaccurate (Wu et al., 2013). Considering these points, the greatest challenges educators face regarding using AR is how to increase learning motivation by enhancing the students' sensory experience. The second characteristic of AR is the cooperation between real and virtual objects: The aim of mobile AR is to integrate digital data into the real environment to provide users with an immersive sensory experience (Hwang, Yang, Tsai, & Yang, 2009; Hwang, Tsai, & Yang, 2008; Yang, Okamoto, & Tseng, 2008). Therefore, the virtual object must be presented accurately in the real geographical location; this is the essence of the navigating mechanism. In a virtual or augmented scenario, the navigating mechanism does not actively interact with the user or provide accurate information; instead, it passively interacts with and provides information to the user (Kye & Kim, 2008; Burigat & Chittaro, 2007). The final characteristic is that real and virtual objects must interact in real-time: the mobile AR scenario supports three types of interaction. The first is the interaction between the student and the learning content. Numerous previous studies have indicated that this type of interaction increases students' cognitive and learning abilities, such as comprehension, memory, and imagination (Dalgarno, 2004). The other two types are the interaction between the student and the learning aids, and the interaction between students. These two types of interaction enable students to identify solutions to problems in the scenario through cooperation and teamwork.

Educators and researchers anticipate applying emerging technologies, such as AR and multiple-user VR, to teaching and learning activities (Bower, 2008; Dalgarno & Lee, 2010; Dunleavy et al., 2009; Kye & Kim, 2008). The sensory experience and interaction and guiding functions of these technologies can improve students’ learning satisfaction and enable them to structure their knowledge and complete the learning tasks (Dalgarno & Lee, 2010; Dunleavy et al., 2009). Furthermore, a number of researchers have proposed that mobile AR devices have unique applications in education, such as improving the success rate of physical interaction-related learning tasks and supporting memory-related learning activities (Chien, Chen, & Jeng, 2010; Dunleavy et al., 2009).

Augmented reality-based mobile learning approach

The AR-based mobile learning system was developed using JAVA for the website, Oracle for the database, and Xcode for the iPad mini devices. Figure 1 shows the structure of the system, which consists of a location, a camera, image editing, a digital compass, a three-axis gyro, an accelerometer and an AR display module.

The location module is able to detect the GPS location of the students, guide them to find the target ecology areas, and show them the corresponding learning tasks or related learning materials. The camera and image editing modules
are able to capture the image from the authentic environment and to annotate and comment on the image of the observed objects when students investigate different characteristics of learning objects. The edited images, comments, annotations, and GPS location data are uploaded to the media server by WIFI communication networks. The digital compass and the three-axis gyro are able to distinguish the direction and relative positions of the students and learning objects. The accelerometer module allows students to shake their iPad to catch the authentic image through small micro electro-mechanical systems. Finally, the AR display module, according to the different locations of the learning objects, shows the integrated images consisting of the target learning objects, edited images and relevant information, on the screen of the mobile device.

Figure 1. System structure of the interactive AR-based mobile learning

Figure 2 shows the basic functions of the interactive AR-based mobile learning system, which consists of an AR-based mobile learning function, an online chat room function and an investigated portfolio function. The AR-based mobile learning function allows students to learn about the target learning objects, to link to the supplementary materials, to capture their observations, to annotate and to comment on the images, and to browse other students’ observations. The online chat room function allows students to discuss their investigation immediately from different locations. The investigated portfolio function collects each user’s observed portfolio, participated portfolio and reflected portfolio.
Figure 2. Interface of the interactive AR-based mobile learning

Figure 3. Example of providing AR information
Figure 3 shows an illustrative example of applying the interactive AR tool. The AR tool in the mobile device integrates images and a description on different layers according to different distances and directions. In the upper right corner of the screen, there is a “rotate” function in order to make it easier for students to alter the overlapping layers. Image-based discussion can prompt students to share more observations and reflections by pressing the image to leave comments. The distance on the image can guide students in the right direction to walk toward, observe, and touch the learning object.

Figure 4. Students’ activity for AR-based mobile learning

Figure 4 shows the flow of the AR-based inquiry-based learning system, which is implemented based on the 5-step learning strategy proposed by Bruce and Bishop (2002):

(1) Ask: The instructor first defines the learning objects and allows students to search for them to cultivate their proactivity. The purpose of this step is to enable students to search for the learning objects, which are then continuously redefined throughout the cycle of the inquiry-based learning. First, students must define the learning objects to be explored. Thus, the instructor provides background knowledge of the learning objects in the class, and by piquing the students’ interest in these objects, their learning motivation is greatly enhanced. Then the instructor guides the students to the set learning scenario using mobile AR, allowing the mobile AR to lead the students to the target learning objects.

(2) Investigate: In this step, students are naturally guided to continuously investigate the learning content by their curiosity. Students can reference the learning aids to understand various aspects of the learning content. When the content is understood, they can redefine the learning object or simplify it by dividing it into smaller components. When students have reached the learning object, the instructor can guide them in observing the environment using the questions presented by the handheld device. Through observation, the students can examine whether the information on the learning object is identical to their knowledge and then, using mobile AR, extend their learning to other concepts of the object. Students can use these extended concepts to conduct deeper observations and exploration.
During the observation process, students can use the camera function to take photographs of the learning object and share their observations with their peers (see Figure 3). They can also employ the footnote function to record their thoughts and examine the accuracy of the results with their peers. Using this technology, students can not only perform inquiry-based learning more easily and increase their understanding of the learning object, but they can also develop teamwork skills that facilitate problem-solving during the learning process (Shih et al., 2010). In addition, students can instantly upload their thoughts and observations, enabling the instructor to constantly monitor their learning progress.

(3) Create: After the inquiry process, the instructor then uses the learning progress system to discuss the concepts related to each learning object with the student. During this process, the instructor redefines the learning objects, enables the students to share their experiences, and stimulates a discussion of relevant ideas. These in-depth cognitive processes allow the students to assimilate the information of the learning object into their own knowledge. This step shows that the role of the instructor is to guide students in developing their knowledge without participating in the actual process. After the completion of learning object investigation, the students form connections among the learning content to create new internalized knowledge.

(4) Share: Following the completion of knowledge construction, students can use the learning progress system to share their learning experiences and perceptions. Through sharing, students can reflect on whether they should adjust their methods for understanding the teaching material and examine whether their ideas correspond with those of their peers. Furthermore, the progress data captured by the learning progress system not only allows effective management of students’ learning objectives but also enables the instructor to identify whether the students are experiencing difficulties during the learning process. Instructors can monitor the students’ learning condition based on their progress, assess whether they should adjust their teaching method, and understand why particular teaching methods cause learning difficulties for students.

(5) Reflect: After sharing their learning experience with their peers, the students reflect on and reconsider their newly acquired knowledge on a deeper level. Reflection is a critical aspect of the learning process (Chi, de Leeuw, Chiu, & Lavancher, 1994), significantly influencing students’ knowledge comprehension and memory. Through reflection exercises, students can revise, examine, and correct their knowledge and perceptions. During the reflection process, knowledge is more easily understood and better comprehended, which improves learning achievement. Reflection also promotes learning independence because it highlights the various levels of a problem, allowing students to examine, evaluate, and understand their thoughts. This increases their involvement in the learning process, enhances their learning motivation, and enables students to become positive, proactive, and responsible self-reflecting individuals. Students can rethink the initially defined learning objects and the direction of inquiry, as well as confirming the accuracy of their conclusions.

**Experiment design**

The experimental material used in this study was a fourth grade natural science unit on aquatic animals and plants, which was divided into four sections: water habitats, different types of aquatic plants, different types of aquatic animals, and the secret of aquatic plants. Each section contains learning themes, for example, water habitats is comprised of the two themes of natural habitats and manmade habitats; natural habitats include lakes, rivers, marshes, coastal intertidal zones, and lake intertidal zones; manmade habitats include ponds, dams, and irrigation ponds. Water plants comprise the following four themes: emergent plants, submerged plants, floating-leaf plants, and floating plants. The inquiry-based learning activity was developed based on the five-step design criteria proposed by Bruce and Bishop (2002), that is “ask,” “investigate,” “create,” “share” and “reflect.”

**Participants**

The participants of this experiment were fourth grade students from an elementary school in Northern Taiwan. A total of 57 students were included in this study, ranging between 9 and 10 years of age. These students were from two classes; one class was set as the experimental group, and the other was the control group. The same instructor was responsible for both classes.
Experimental procedure

Figure 5 shows the experimental procedure. During the learning activity, the instructor used 90 minutes to introduce aquatic plants. Following that, the students took a 30-minute pre-test, which aimed to evaluate whether the two groups of students had an equivalent basic prior knowledge of the natural science course content. The students in both groups were trained to operate the mobile learning devices before the 120-minute inquiry-based investigation. During the learning activity, the students in the experimental group learned with the AR-based mobile learning approach. On the other hand, those in the control group learned with the inquiry-based mobile learning approach; that is, the instructor provided mobile devices and engaged the students in inquiry-based learning activities for investigating the issues of water hyacinths and their distribution.

The learning materials included text descriptions and pictures of the plant characteristics. For example, water hyacinths are aquatic plants and are pale purple in color. After presenting a film on water hyacinths, the instructor asked the students to examine the plant characteristics based on the information in the film and to record their thoughts on their mobile devices. After exploring the plant characteristics, the instructor let the students discuss concepts related to water hyacinths and encouraged them to discuss their ideas and determine whether their knowledge corresponded with that of their peers using their mobile devices. After the basic concepts regarding water hyacinths were understood, the instructor let the students present other plants that are similar to water hyacinths, such as water lilies and duckweed. Thus, the students could identify the differences between these plants and water hyacinths, enabling them to learn the characteristics of other plants and reinforcing their knowledge of water hyacinths.

![Diagram of the experimental procedure](image-url)

Figure 5. The experimental procedure

Measuring tools

To assess the students' learning achievements, a pre-test was conducted to ensure that the two groups of students had equivalent prior knowledge before the learning activity. It consisted of thirty multiple-choice items with a perfect score of 100. Moreover, a post-test was conducted for assessing the students’ learning achievements after the learning activity. It consisted of thirty multiple-choice items for assessing the students’ knowledge for identifying and differentiating the plants on the school campus with a perfect score of 100. Both the pre-test and the post-test were developed by two experienced teachers who had more than 5 years experience in teaching the natural science course.
The learning motivation questionnaire was modified from the measure developed by Keller (2010) based on the ARCS (Attention, Relevance, Confidence, and Satisfaction) model of motivational design (Keller, 1987). A total of 36 questions in four dimensions were employed and assessed using a five-point Likert scale; that is, the design of the learning activities must attract the students’ attention (Attention), the learning activities and materials have to be relevant to the students (Relevance), the students have to be confident with the learning activities (Confidence), and the students need to feel satisfied after completing the learning activities (Satisfaction). The Cronbach’s α values of the four dimensions were 0.80, 0.78, 0.65 and 0.82, respectively.

The cognitive load survey developed by Sweller, van Merriënboer and Paas (1998) was used to measure the cognitive load of individual students. The main purpose of the questionnaire was to assess whether using a tablet computer as a learning tool generates cognitive load. The questionnaire covers four questions; two measure the students’ mental load and the other two measure their mental effort using a five-point scale. The Cronbach’s α values of the two dimensions were 0.845 and 0.85, respectively.

Analysis and results

Learning achievement

Before the experiment, the two groups took a pre-test to ensure that they had equal abilities in this subject before the learning activity. The means and standard deviations of the pre-test were 46.46 and 13.220 for the experimental group, and 44.97 and 15.546 for the control group. The t-test result showed that these two groups did not differ significantly (t = 0.391, p > .05); that is, the two groups of students had statistically equivalent abilities before learning the subject unit.

After participating in the learning activity, the two groups of students took a post-test. The t-test result shows that the average learning achievement of the experimental group was significantly better than that of the control group (t = 2.046, p < .05), as shown in Table 1. From the above results, it is concluded that the mobile AR approach is helpful to the students in improving their inquiry-based learning achievements.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>Std. error</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-test</td>
<td>Experimental group</td>
<td>28</td>
<td>80.14</td>
<td>8.763</td>
<td>1.656</td>
<td>2.046</td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>29</td>
<td>73.93</td>
<td>13.703</td>
<td>2.545</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05.

Learning motivation

Table 2 shows the t-test result of the learning motivation of the two groups. The t-test result showed that the difference between the learning motivations of the two groups was significant (t = 2.99, p < .01); moreover, the mean value of the experimental group (i.e., 4.05) was higher than that of the control group (i.e., 3.63), implying that the mobile AR approach can promote students’ motivations in inquiry-based learning activities.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation</td>
<td>Experimental group</td>
<td>28</td>
<td>4.05</td>
<td>0.07</td>
<td>2.99**</td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>29</td>
<td>3.63</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

** p < .01.

Table 3 further shows descriptive statistics for the four subscales of the ARCS model used to describe motivation. It was found that the mean values for attention, confidence and relevance of the experimental group were significantly higher than those of the control group.
The primary objective of the Attention subscale of the ARCS model of motivation was to assess the students’ attention regarding the learning material and learning activities. In the interviews, the students in the experimental group indicated that the virtual learning material presented through the mobile AR scenario enabled them to focus on exploring the characteristics of plants because they did not need to spend time linking the digital supplementary materials or instructions from the mobile learning system to the real-world contexts. The students also indicated that mobile AR allowed them to access learning materials and learning tasks immediately, regardless of their real-world locations, and hence they would proactively attempt to understand the learning content provided by the learning system and the surrounding real-world learning objects.

The relevance hypothesis of the ARCS model of motivation was used to assess the relevance of the learning tasks and the provided materials. It was found that the students in the experimental group gave significantly higher ratings than those in the control group in this dimension since the mobile AR approach provided immediate and relevant information and guidance to the students based on their real-world locations and contexts, which was highly beneficial to them for their outdoor observations and learning. On the other hand, those in the control group needed to search for relevant information regarding their learning contexts on their own, which lowered their learning motivation to some extent.

The confidence hypothesis of the ARCS model of motivation was used to assess the students’ confidence regarding the learning activities and their level of anticipation. In the interviews, the experimental group students indicated that mobile AR could actively provide support or guidance related to the real-world contexts. Such an integration of real-world contexts and digital-assistance was helpful to them in facing the challenges of the learning tasks, and hence could promote their confidence regarding the learning activities.

The satisfaction hypothesis of the ARCS model of motivation was used to assess the students’ feeling of satisfaction after completing the learning activities. As both groups of students were equipped with the same mobile devices with digital supplementary materials regarding the aquatic plants, all of the students showed a high level of satisfaction in using the mobile devices to learn, resulting in no significant difference in this dimension.

### Cognitive load

The aim of using the cognitive load measure was to evaluate whether the students’ performances were affected owing to improper educational settings, including the difficulty levels of the selected learning materials and the learning strategies adopted. The experimental results showed that the means and SD values were 2.02 and 0.83 for the experimental group, and 2.27 and 0.79 for the control group. Moreover, the t-test results for the cognitive loads of the two groups were $t = -1.168$ and $p > .05$, indicating that the two groups’ cognitive loads did not differ significantly.

The cognitive load measure consisted of two dimensions: mental load and mental effort. An in-depth analysis was further conducted on these two dimensions. Mental load refers to the internal aspects of cognitive load; specifically, when students face a large amount of learning content or difficult content beyond their information processing abilities or knowledge levels, they may perceive an excessive cognitive load. For mental load, the experimental group’s mean = 2.23 and $SD = 0.98$, while the control group’s mean = 2.24 and $SD = 0.90$. The t-test results showed that $t = -0.037$, $p > .05$, which indicates no significant difference between the two groups’ mental load. This finding is reasonable since both groups of students were situated to complete the same learning tasks with identical

### Table 3. t-test results of the four subscales of learning motivation for the two groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention</td>
<td>Experimental</td>
<td>28</td>
<td>4.08</td>
<td>0.41</td>
<td>2.50*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>29</td>
<td>3.69</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Relevance</td>
<td>Experimental</td>
<td>28</td>
<td>4.11</td>
<td>0.41</td>
<td>3.36**</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>29</td>
<td>3.58</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td>Experimental</td>
<td>28</td>
<td>3.87</td>
<td>0.45</td>
<td>2.34**</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>29</td>
<td>3.50</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Experimental</td>
<td>28</td>
<td>4.12</td>
<td>0.44</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>29</td>
<td>3.72</td>
<td>1.01</td>
<td></td>
</tr>
</tbody>
</table>

* $p < .05$. ** $p < .01$. 

The relevance hypothesis of the ARCS model of motivation was used to assess the relevance of the learning tasks and the provided materials. It was found that the students in the experimental group gave significantly higher ratings than those in the control group in this dimension since the mobile AR approach provided immediate and relevant information and guidance to the students based on their real-world locations and contexts, which was highly beneficial to them for their outdoor observations and learning. On the other hand, those in the control group needed to search for relevant information regarding their learning contexts on their own, which lowered their learning motivation to some extent.

The confidence hypothesis of the ARCS model of motivation was used to assess the students’ confidence regarding the learning activities and their level of anticipation. In the interviews, the experimental group students indicated that mobile AR could actively provide support or guidance related to the real-world contexts. Such an integration of real-world contexts and digital-assistance was helpful to them in facing the challenges of the learning tasks, and hence could promote their confidence regarding the learning activities.

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### Cognitive load

The aim of using the cognitive load measure was to evaluate whether the students’ performances were affected owing to improper educational settings, including the difficulty levels of the selected learning materials and the learning strategies adopted. The experimental results showed that the means and SD values were 2.02 and 0.83 for the experimental group, and 2.27 and 0.79 for the control group. Moreover, the t-test results for the cognitive loads of the two groups were $t = -1.168$ and $p > .05$, indicating that the two groups’ cognitive loads did not differ significantly.

The cognitive load measure consisted of two dimensions: mental load and mental effort. An in-depth analysis was further conducted on these two dimensions. Mental load refers to the internal aspects of cognitive load; specifically, when students face a large amount of learning content or difficult content beyond their information processing abilities or knowledge levels, they may perceive an excessive cognitive load. For mental load, the experimental group’s mean = 2.23 and $SD = 0.98$, while the control group’s mean = 2.24 and $SD = 0.90$. The t-test results showed that $t = -0.037$, $p > .05$, which indicates no significant difference between the two groups’ mental load. This finding is reasonable since both groups of students were situated to complete the same learning tasks with identical
Mental effort refers to whether the students must exert more mental effort to understand the learning materials. Table 4 shows the experimental group’s mean = 1.80 and SD = 0.91, while the control group’s mean = 2.29 and SD = 0.99. The t-test analysis results showed that $t = -1.949$, $p > .05$, indicating that no significant difference was found. From the means of the two groups, it was found that the mental effort of the students who learned with the mobile AR approach showed slightly lower mental effort, which might be attributed to the use of the AR technology in helping them link the real-world contexts with supplementary materials at the right place and the right time.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>t</th>
</tr>
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<tbody>
<tr>
<td>Mental load</td>
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<td>28</td>
<td>2.23</td>
<td>0.98</td>
<td>-0.037</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>29</td>
<td>2.24</td>
<td>0.90</td>
<td></td>
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<tr>
<td>Mental effort</td>
<td>Experimental</td>
<td>28</td>
<td>1.80</td>
<td>0.91</td>
<td>-1.949</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>29</td>
<td>2.29</td>
<td>0.99</td>
<td></td>
</tr>
</tbody>
</table>

**Discussion and conclusions**

In this study, a mobile AR approach is proposed for conducting inquiry-based learning activities. A learning system was developed based on the proposed approach and an experiment has been conducted to evaluate the effectiveness of the approach in an elementary school natural science course. The experimental results show that the mobile AR approach is able to improve students’ learning performance in inquiry-based learning activities owing to the use of AR technology in linking the real-world contexts with the digital learning resources at the right place and the right time. Such a result can be explained by spatial and temporal continuity principles of the multimedia design theory proposed by Mayer (2001) and Mayer and Moreno (2003); that is, learning from learning scenarios that present relevant materials (e.g., images, texts, videos) in a well integrated and organized form can avoid creating incidental cognitive load, and hence benefits students in improving their learning performance. Similar findings have been reported by Liu, Lin, Tsai and Paas (2012) in web-based learning activities. When learning with the AR-based mobile learning system, the students learned from the scenarios that presented the real-world targets and the supplementary digital materials in an integrated and organized way. On the other hand, in a traditional instruction approach or a conventional mobile learning approach, the real-world targets and the corresponding materials are presented separately and asynchronously. When observing the real-world targets, the students need to read the corresponding materials from a mobile device or a printed sheet and put lots of efforts on organizing the information by themselves, which prevents them from viewing the learning targets and thinking in a higher order manner.

In addition, the experimental results indicate that the experimental group students gained significant learning motivation for attention, relevance, confidence and a high level of satisfaction in using the AR-based mobile devices to learn. According to the interviews, students in the experimental group thought the AR-based mobile learning felt interesting and useful for assisting them to learn. Moreover, students pointed out that using the AR-based mobile learning to conduct inquiry-based learning can not only provide opportunities to practice, but also to engage in enjoyable experiences for assisting Inquiring. Students were excited and gained a feeling for the interesting in real-world environments when taking photos, making fancy notations on photos, sending to the AR-based learning system from different places or sharing their comments with classmates. Therefore, the students had a positive learning motivation toward using AR-based mobile learning to aid natural science learning and were also satisfied with its effectiveness.

Although the AR-based mobile learning system benefited the students in this application, there are some limitations to be noted. First, the GPS accuracy of the mobile devices limits the display of the location of the learning objects; therefore, when designing a learning task, the teachers need to consider the size of the learning objects and the distance between them. Moreover, to provide instant hints or learning guidance to individual students, the teachers need to spend time developing learning processes for evaluation purposes, and digital learning materials to provide learning supports.

In the near future, we will try to apply this approach to other mobile learning applications, including the natural science courses and local culture courses of elementary and high schools. Moreover, we plan to explore the
behavioral patterns of an online knowledge-sharing discussion activity for inquiry-based learning courses and explore the performance of using AR-based mobile learning for different learning styles or different cognitive styles. Adopting different learning devices, such as Google Glass, can also become one of our research directions.

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