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An augmented reality-based learning approach to enhancing students' science reading performances from the perspective of the cognitive load theory

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Abstract

Reading has been regarded as a medium for learning science, revealing the importance of enhancing learners' reading competence in science education. The critical features of science texts are their multiple representations, such as text and visual elements, which assist the representation of science concepts. A multimedia learning environment can present relevant materials in various formats and help students to process the materials in meaningful ways, for example, by integrating learning materials with relevant prior concepts, and organizing them into a consistent and coherent cognitive structure. However, some issues with multimedia instructional design have been proposed, such as students' cognitive load and learning motivations. In this study, an augmented reality-based science learning system was developed based on the contiguity principle of multimedia learning in order to promote students' science learning. Moreover, an experiment was conducted on a natural science course in an elementary school to assess the effectiveness of the implemented system on students' learning. The experimental results display that the students learning with this approach found made significant gains in their learning achievements and motivations compared to those learning science with conventional multimedia science learning; moreover, their perceptions of extraneous cognitive load were significantly reduced during the learning activity.

Introduction

Several previous studies have advanced the significance of reading competence in science education for conceptual and theoretical comprehension (Yang, Chang, Chen, & Chen, 2016). Researchers have asserted that readers can construct meaning by assimilating text information with their relevant background beliefs or knowledge (Wang & Chen, 2014). Moreover, science

Practitioner Notes

What is already known about this topic

- Multimedia learning environments can offer potential affordances for facilitating students' concept understanding.
- The advancements in mobile technologies have enabled teachers to design rich multimedia learning environments via immediately dynamic representations.
- Some challenges concerning the instructional design of multimedia have arisen, including issues related to cognitive load.

What this paper adds

- An augmented reality-based science learning approach was developed based on the contiguity principle of multimedia learning.
- An augmented reality-based science learning system was designed based on the implemented approach.
- It was displayed that the approach improved students' learning achievements and motivations.
- Students' perceptions of extraneous cognitive load were significantly reduced during the augmented reality-based science learning activity.

Implications for practice and/or policy

- This study demonstrated the positive influence of augmented reality on a multimedia learning situation.
- The augmented reality-based science learning approach could be a valuable reference for projecting a multimedia learning environment.

reading concerns metacognitive processes and active knowledge construction via revisiting concepts connected to experienced authentic phenomena (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012). Reading has been regarded as a medium for learning science and as being essential to scientific works (Hung, 2014), revealing the importance of enhancing learners' reading competence in science education.

Reading competence has become increasingly crucial due to the advances in information technologies which facilitate easier access to information (Yang et al., 2016). The critical features of science texts are the multiple representations, such as text and visual elements, which assist the representation of science concepts (Hung, 2014). For example, Mason, Tornatora and Pluchino (2013) asserted that visualizations play a significant role in science learning because they make complex processes visible. Thus, it is necessary for teachers to assist students with an environment consisting of various kinds of information. Multimedia learning refers to an environment for constructing different types of mental representations by assisting students with various kinds of media materials, such as texts and pictures (Eitel, Scheiter, Schüler, Nyström, & Holmqvist, 2013). Moreover, the advancements in mobile technologies have enabled teachers to design rich multimedia learning environments via immediately dynamic representations. For example, Wang, Chen, Fang and Chou (2014) described that the increasing use of digital technologies has supplied students with an information-driven environment to enhance their reading proficiency. However, despite the advantages of multimedia which facilitate learning, some challenges concerning the instructional design of multimedia have arisen, including issues related to cognitive load (Knörzer, Brünken, & Park, 2016).

Cognitive load is regarded as a kind of multidimensional construct representation of the load on the students' cognitive system as they are executing specific tasks (Paas & van Merriënboer, 1994). Cognitive load theory emphasizes the significance of interacting between a learning task and the learners' limited working memory (Ayres, 2006), and describes three types of cognitive load, namely intrinsic, extraneous, and germane load. Identifying the relation between total cognitive load and an instructional design is critical due to the restricted capacity of learners' working memory (Blayney, Kalyuga, & Sweller, 2015). Some previous studies have stressed the significance of adequately designed multimedia instructional activities. For example, Hung (2014) illustrated that students seek data from both the print-based channel and the visual channel for making sense of a science text, and the integration of the two channels also involves students' prior knowledge of the learning concepts. Thus, it is meaningful for teachers to design multimedia instructional activities carefully, using the advantages of the technologies at their disposal.

In education, augmented reality (AR) has been considered as a system which can integrate virtual elements with the physical environment for linking what students observe in real-world environments to their prior knowledge (Bower, Lee, & Dalgarno, 2017). With the use of AR technology, students' interactions, engagement, and experiences can be enhanced for science learning. For example, Yoon, Anderson, Lin, and Elinich (2017) likewise improved students' knowledge of Bernoulli's principle by allowing them to interact with an AR device. In this study, an AR system based on multimedia learning was designed to support students in science reading and to enhance their learning effectiveness.

Literature review

Science reading could potentially effective if a student inferentially links between the relevant knowledge and the text (Phillips & Norris, 2009). Moreover, multiple representations relate to the reader's prior knowledge of the science concepts to facilitate the representation and science learning (Hung, 2014). Multimedia learning occurs when students simultaneously obtain information in all sorts of formats, such as text, pictures, animation, and video (Mayer, 1997). Multimedia learning refers to a multistage cognitive process during which some types of cognitive representation are constructed via various kinds of media materials (Eitel et al., 2013). Thanks to the considerable advances in computer technologies, computer-based multimedia learning environments now offer potential affordances for facilitating students' concept understanding. Some previous research has explored the impacts of multimedia learning on education, such as transfer test performance, mental effort, and higher-order thinking skills (Arslan-Ari, 2018; Chung, Cheon, & Lee, 2015). For example, She and Chen (2009) investigated the impact of multimedia effects on science learning, and stated that the students that learned with animation with narration outperformed those that used animation with on-screen text, in terms of their immediate and long-term retention.

Multimedia offers a kind of effective learning environment by combining a variety of formats such as text, pictures, animations, audio, and videos (Doolittle, Bryant, & Chittum, 2015). A multimedia learning environment can present relevant materials in various formats and help students process the materials in meaningful ways, for example, by integrating learning materials with relevant prior concepts, and organizing them into a consistent and coherent cognitive structure. Moreover, Mayer (2003) noted that the multimedia effect produces better learning results when it integrates pictures with words rather than just setting words in a computer-based or a book-based environment.

Meaningful learning requires students' engagement in considerable cognitive processing during learning activities, but their capacity for cognitive processing is a severe restriction (Blayney et al., 2015). This means that teachers must identify and consider the demands of cognitive load while designing multimedia instruction. Cognitive load is referred to as a kind of multidimensional construct representation of the load which is imposed on students' cognitive systems while conducting a specific task (Paas & van Merriënboer, 1994). Cognitive load theory claims the significant role of the interactions between a learning task and students' limited working memory (Ayres, 2006), illustrating the assessable dimensions of mental load, mental effort, and performance. These dimensions, respectively, correspond to three types of cognitive load, namely intrinsic, extraneous, and germane cognitive load, which make up the total cognitive load. Intrinsic cognitive load refers to an inherent component of the materials itself and to the degree of the learners' prior knowledge or experience (Cheng, Lu, & Yang, 2015). Extraneous cognitive load is generated from that part of the instructional design which induces excess information processing and can be modified, while germane cognitive load is considered as the amount of working memory capacity needed to deal with intrinsic load (Leahy & Sweller, 2016).

When more working memory resources are utilized to cope with the interacting elements related to intrinsic cognitive load, and fewer are used to deal with those regarding extraneous cognitive load, the instruction will be more effective (Paas & Sweller, 2014). The total cognitive load cannot exceed a student's working memory capacity, indicating the significance of identifying the association of total cognitive load with an instructional design. On the other hand, in Mayer's (2014a) study of cognitive theory of multimedia learning, he asserted that, for constructing a coherent mental representation, humans are actively involved in cognitive processing, including "paying attention to relevant incoming information, organizing incoming information into a coherent cognitive structure, and integrating incoming information with other knowledge" (p. 50). Therefore, to acquire the potential positive impacts of multimedia learning, it is significant to carefully design a learning activity that may involve students' cognitive load.

A great deal of the previous research has illustrated various ways of properly designing multimedia instructional activities. A study on reviewing the design of multimedia explanations conducted by Mayer (2003) described the effect of multimedia instruction on learning, including a multimedia effect, a coherence effect, a spatial contiguity effect and a personalization effect. Among these effects, the spatial contiguity effect or principle states that simultaneously displaying corresponding pictures and words is better than displaying them separately in a multimedia presentation design based on reducing extraneous cognitive load (Brunken, Plass, & Leutner, 2003). Furthermore, Türk and Erçetin (2014) designed the presentations of multimedia information for improving students' English vocabulary learning and reading comprehension based on the temporal contiguity principle, finding that simultaneously displaying verbal and visual materials can reduce students' cognitive load and enhance their learning.

Moreover, some previous research has asserted that learners' emotions play a crucial role in multimedia learning (Knörzer et al., 2016). Emotional awareness when designing multimedia learning materials can arouse students' positive emotions which will assist the learning process (Heidig, Müller, & Reichelt, 2015). Mayer (2014b) proposed that motivational features can help students engage in learning processes and improve their learning if they are not overloaded with or distracted from processing the content. As mentioned above, it is worth probing students' motivational state and their cognitive load during multimedia learning activities.

AR is referred to as a system which can integrate virtual (computer-generated) elements or information with physical environments (Azuma et al., 2001). Azuma (1997) considered AR as a variation of virtual environments, which consist of three characteristics: "being interactive in real time," "combining real and virtual," and "being registered in three dimensions." AR can afford students with potential opportunities for linking what they observe in authentic environments to their prior learning concepts by both visualization and interaction. For example, Yilmaz, Kucuk, and Goktas (2017) investigated the effectiveness of AR picture books (ARPB) on preschool children's reading attitudes and story comprehension performance. Most of them expressed their enjoyment while using the ARPB, and displayed high story comprehension performance. Moreover, Yoon et al. (2017) described how AR has evidenced its advantages by means of augmenting students' interactions, engagement, and experiences in science learning. Specifically, combining multiple data sources with a well-designed presentation in an AR learning environment can reduce the participants' cognitive workload (Wei, Weng, Liu, & Wang, 2015).

AR has been widely adopted in education due to the popularization of mobile technology (Nadolny, 2017), and has demonstrated positive influences on conceptual understanding, learning experience, as well as motivation improvement (Cheng & Tsai, 2013). Furthermore, a systematic review conducted by Ibáñez and Delgado-Kloos (2018) analyzed the 28 papers from 2010 to 2017 on AR-based learning in science, technology, engineering, and mathematics (STEM). They asserted that most of the studies investigated the influences of AR on students' conceptual understanding, followed by those that surveyed affect in AR-based learning. For example, Akçayır, Akçayır, Pektaş, and Ocak (2016) probed the influence of utilizing AR technologies on students' science learning and found that AR can improve students' laboratory skills as well as their positive learning attitudes.

However, few studies have probed the application of AR in education from the perspective of multimedia learning and cognitive load. A systematic review, executed by Akçayır and Akçayır (2017) examined the 68 research articles on AR-based educational settings in the SSCI journals, and found that promoting learning achievements was the most mentioned advantage of AR technology. Only four of the 68 papers presented the information about cognitive load, and contradictory results were yielded—two papers declared that it decreased cognitive load, while the other one asserted that AR increased cognitive overload. Cheng (2017) conducted a quantitative study of 153 students' perceptions of reading an AR book, and described that the students were aware of stronger motivation, more positive attitudes and lower cognitive load during the AR book reading activity. He further indicated that cognitive load can predict the students' behavioral intentions when their perceptions of the factors of motivation, for example attention or confidence, were significant. Therefore, it is crucial to probe the role of motivational factors and cognitive load in AR-based learning environments.

Research Questions

In this study, an AR-based learning approach integrated with multimedia materials, based on the contiguity effect of multimedia instruction, was designed for the students' science textbook. It is called the AR multimedia textbook (ARMTB). Moreover, an experiment was conducted to explore the effects of the implemented approach on elementary school students' learning achievements and motivations. The study also probes their perceptions of cognitive load during the learning activity. The learning effectiveness was evaluated via answering the following research questions.

1. Do the students using the ARMTB approach outperform those learning science with the conventional multimedia science learning in terms of their learning achievements?
2. Do the students using the ARMTB approach reveal higher learning motivations than those learning science with the conventional multimedia science learning?
3. Can the ARMTB approach reduce the students' cognitive load in comparison with the conventional multimedia science learning?

Development of the AR-based science learning system

In this study, an AR-based science learning system was developed based on the contiguity principle of multimedia learning in order to promote students' science learning. The learning system was designed using Unity 3D and Vuforia. Figure 1 depicts the structure of the learning system which consists of several databases and two learning mechanisms, the "Student learning mechanism" and the "AR-based learning mechanism."

The AR-based learning mechanism is composed of the AR module, the multimedia controlling module, and the 3D object controlling module. As presented in Figure 2, the 3D objects are designed for augmenting students' awareness of the real object. On the other hand, the student learning mechanism is comprised of the problem-based learning module, the instant response module, and the scoring module. Furthermore, five databases are programmed to sustain the learning mechanisms, including the learning portfolio, the item bank, the student profile, the learning material, and the 3D object database.

Individual students are furnished with a mobile device and a textbook about topography. The students utilize the mobile devices to interact with the AR-based science learning system and the textbook. In the learning activity, the students need to read the whole textbook. Once a student reads a highlighted phrase printed in red, he/she can operate the AR-based learning system to obtain multimedia learning materials via the AR module and the multimedia controlling module. A related picture dynamically overlaps on the textbook immediately after the scan. As shown in Figure 3, a picture of alpine terrain overlaps the textbook after a student scans the phrase shown in red, alpine terrain.

Once any picture of the topography mentioned in the textbook is scanned by the learning system, the related 3D object dynamically overlaps on the textbook provided by the 3D object controlling module and the AR module. As depicted in Figure 4, a 3D model of a basin overlaps the textbooks after the picture of the basin is scanned.

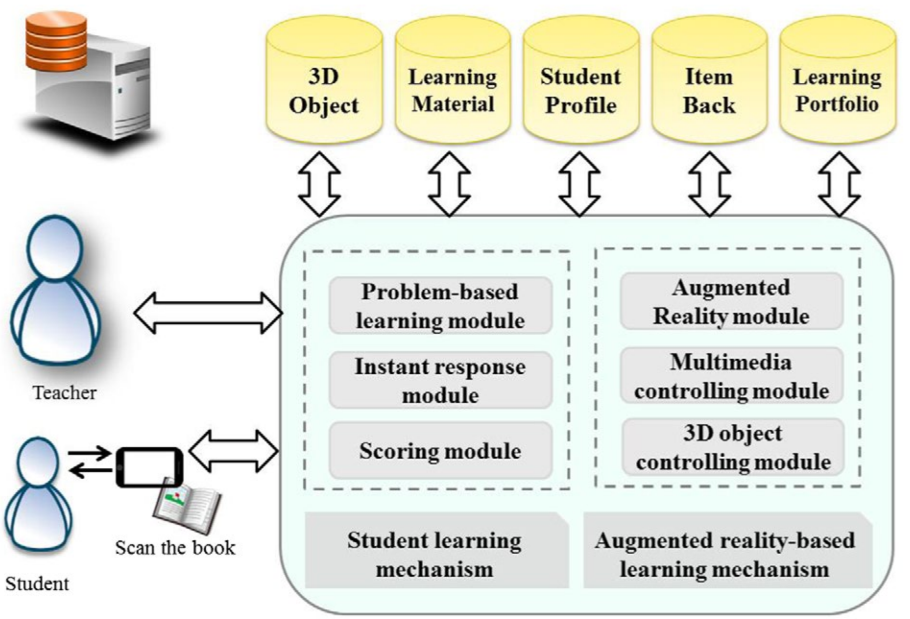

Figure 1: The structure of the AR-based science learning system

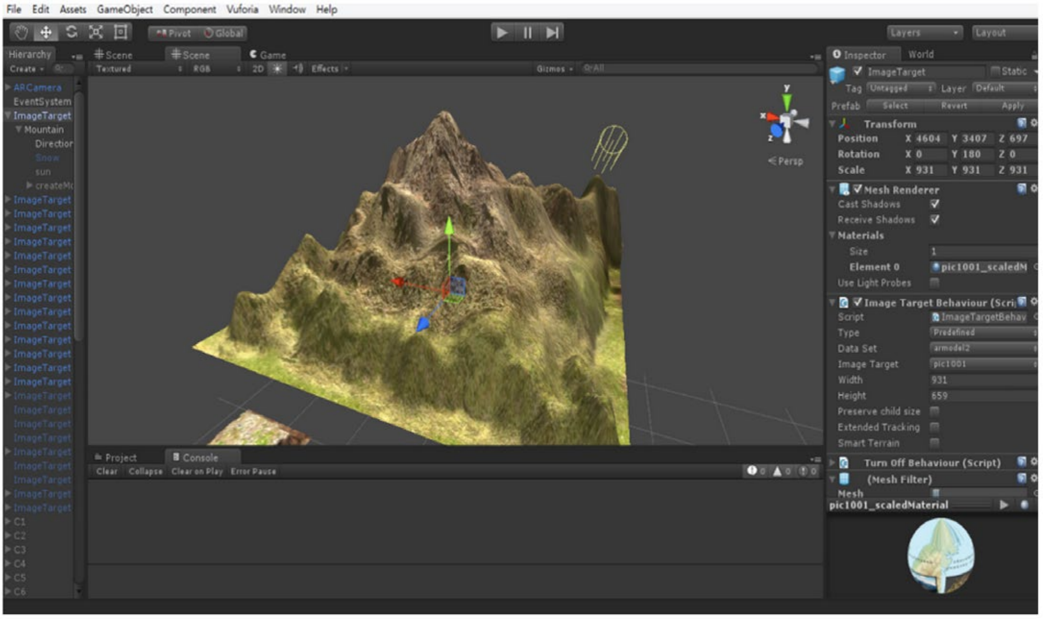

Figure 2: A 3D object for stimulating students' perceptions

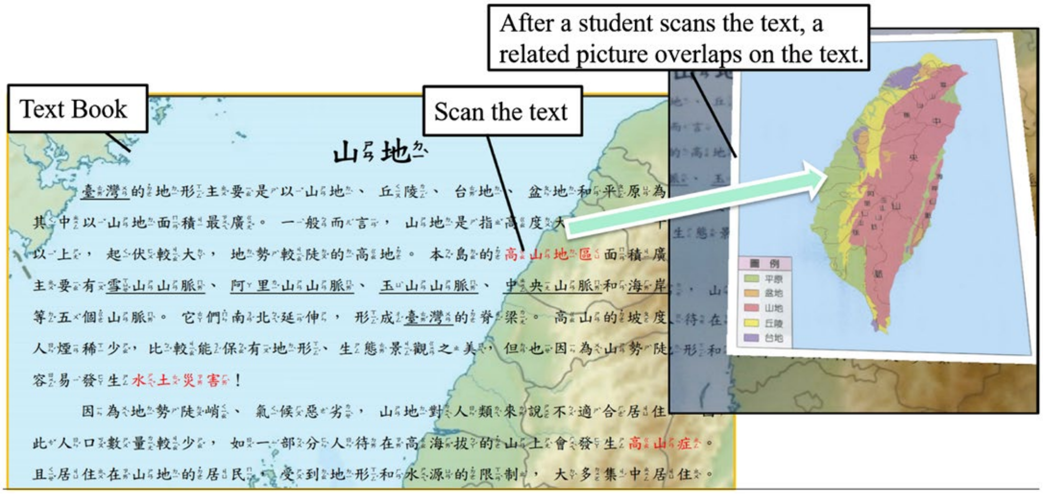

Figure 3: A related picture overlaps on the textbook immediately after the scan

After completing the reality-based science learning, the students immediately work on the problem-based learning tasks regarding the topography being studied. During the learning tasks, individual students will receive related prompt feedback and points from the instant response module and the scoring module, respectively.

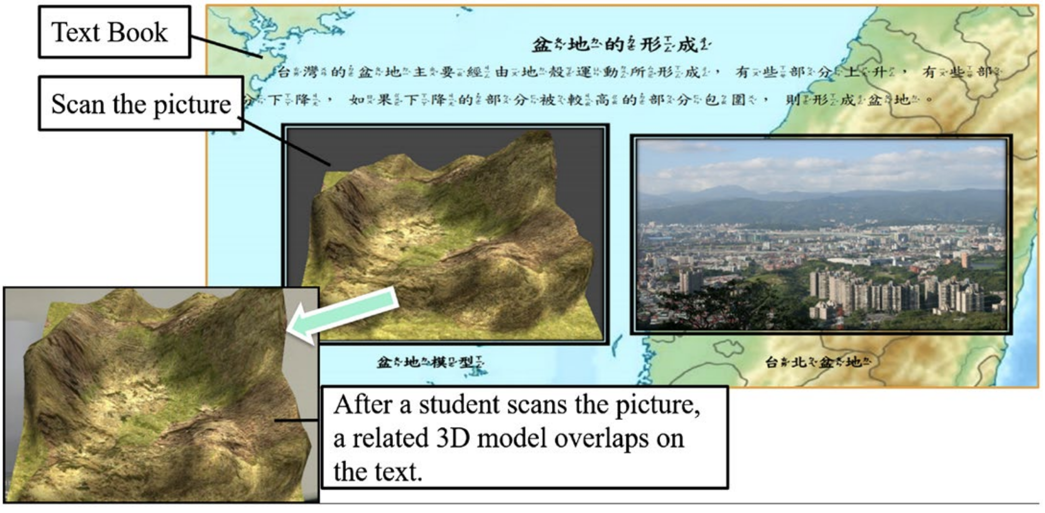

Figure 4: A related picture overlaps on the textbook immediately after the scan

Method

Participants

From two classes of fifth graders (10- or 11-year-olds) in an elementary school in Taiwan, 46 students participated in the learning activities in this study. The two classes were allocated to be the experimental group (n = 23) and the control group (n = 23). The experimental group conducted the learning activity with AR-based science learning; on the other hand, the control group studied the course using conventional multimedia for science learning. All participants took natural science courses for four periods a week and were instructed by the same teacher who has rich experience in science teaching. Furthermore, the students were already familiar with mobile technology, multimedia learning, and AR-based learning.

Experimental procedure

In this study, the experiment was conducted on the natural science course in an elementary school, which aimed to enhance the students' science reading effectiveness. Figure 5 depicts the experimental procedure. Firstly, all participants took the pretest to evaluate their basic knowledge of geography before the learning activity.

Following that, all participants implemented the learning activities for 80 minutes. During the learning activities, the experimental group adopted the AR-based science learning (as shown in Figure 6), while the control group utilized the conventional multimedia science learning. The printed textbook, multimedia materials, and tasks for both groups were identical except for the 3D objects.

After completing the learning activity, all participants conducted the posttest and filled out the questionnaires related to motivation and cognitive load. Afterward, the experiment procedure ended in a one-on-one interview, which probed the views of six students randomly recruited from each of the learning approach groups.

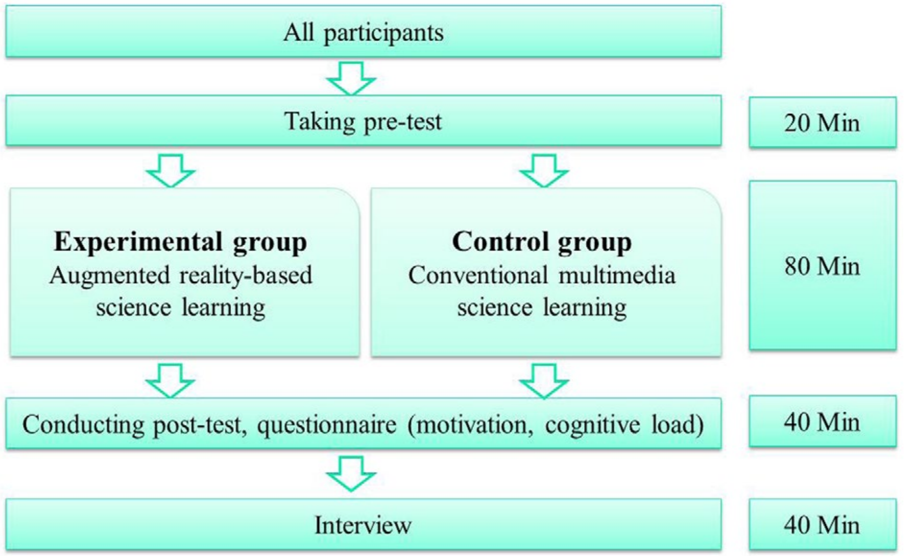

Figure 5: The procedure of the experiment for the learning activity

Figure 6: The scenarios of the AR-based science learning activity

Measuring tools

The measuring tools in this study were composed of the posttest and the surveys of learning motivations and cognitive load.

The pretest aimed to assess the students' fundamental knowledge of the geography before participating in the learning activity. It comprised 20 multiple-choice items. Moreover, the posttest, which consisted of 20 multiple-choice items, was used to evaluate what the participants had learned during the learning activity. Both tests were scored on a scale of 0–100. To confirm the validity and reliability of all of the items, two expert teachers with more than 10 years' experience in teaching elementary schools' natural science courses evaluated all items' content validity; furthermore, via the KR20 analysis, the reliability coefficient of the pretest and the post-test, respectively, were 0.83 and 0.79, indicating the sufficient reliability of the tests.

Keller's ARCS Model (1987), which aims at creating and maintaining motivational environments as well as the meaningfulness of instruction (Shellnut, Knowltion, & Savage, 1999), was utilized to evaluate the students' learning motivations in this study. The survey of learning motivations was adopted from the "Instructional Materials Motivation Survey, IMMS" developed by Keller (2010). The original IMMS comprised four dimensions, namely "Attention," "Relevance," "Confidence," and "Satisfaction." The surveys of learning motivations consisted of 36 items with a 5-point rating scale. Moreover, the attention dimension included 12 items, such as "These multimedia materials caught my eye," and "The way the learning materials are presented on the textbook helped keep my attention." The relevance dimension consisted of nine items. Two example items are "There were examples, or pictures that can display for me how these learning materials could be significant to some people" and "The content of these learning materials is related to my interests." The confidence dimension comprised nine items, such as "After studying for this course, I am confident that I could pass an examination on the related content" and "The good organization of the content helped me feel confident that I would learn this material." Furthermore, a total of six items (eg, "I enjoyed this course so much that I would like to learn more about this topic" and "I would propose this learning approach to others") made up the satisfaction dimension. The Cronbach's alpha coefficients provided by the original measurement for the dimensions were .89, .81, .90, and .92, respectively, while the reliability coefficient of the total scale was .96, indicating highly acceptable reliability in internal consistency of the learning motivations survey.

The survey of cognitive load was modified from the study of Hwang, Yang, and Wang (2013), using a 5-point Likert rating scheme. It comprised two dimensions, "mental effort" and "mental load" which were, respectively, applied for displaying students' extraneous cognitive load and intrinsic cognitive load. Mental effort can be measured when students are executing a task, while mental load originates from the interaction between the task and the characteristics of the learning materials. In this study, the mental effort dimension was made up of three items, such as "I need to make a special effort to complete the learning tasks or obtain the learning achievement in this learning activity"; on the other hand, the mental load dimension consisted of five items (e.g., "I felt frustrated when answering the questions in this learning activity"). The Cronbach's alpha coefficient values described by the original survey were .86 and .85 for the mental load dimension and the mental effort dimension, respectively, indicating high internal consistency reliability for assessing students' cognitive load.

Experimental results

Learning achievement

To explore the influence of the AR-based science learning approach on students' learning achievements, a one-way ANCOVA was conducted. The pretest score was utilized as the covariate for excluding any interference from their prior knowledge; moreover, the learning approach and the posttest score were an independent variable and a dependent variable, respectively.

In order to confirm the reasonableness of the adoption of ANCOVA, the homogeneity test was examined first. It was found that the assumption of homogeneity of regression was not violated

($F = 1.55$, $p > .05$). Following that, the ANCOVA was conducted and the effect is presented in Table 1. A significant effect of the learning approach was verified with $F = 5.03$ ($p < .05$, $\eta^2 = 0.105$), implying that significantly different posttest scores existed between the two groups due to the different learning approaches. Moreover, the adjusted mean values and standard deviation errors of the students' posttest scores were 87.01 and 2.56 for the experimental group and 78.86 and 2.56 for the control group. This result indicates that the AR-based learning approach can improve students' science learning achievements. Moreover, based on the categories stated by Cohen (1988), the effect size (η^2) for the ANCOVA results of the learning approach showed a moderate effect size with $\eta^2 = 0.105$ ($\eta^2 > 0.059$).

Learning motivation

As regards the students' learning motivations, a *t* test was computed to investigate the influence that the AR-based science learning approach had on the participants. As shown in Table 2, a significant difference was confirmed between the two groups ($t = 3.60$; $p < .001$). The means of the students' learning motivation ratings for the experimental and the control groups were, respectively, 4.15 ($SD = 0.48$) and 3.59 ($SD = 0.57$). It was found that the learning motivations of the students using the AR-based science learning approach were significantly higher than those of the students utilizing the conventional multimedia science learning. Moreover, based on the statements described by Cohen (1988), the learning approach displayed a large effect size with $d = 1.06$ ($d > 0.80$).

In this study, the learning motivation questionnaire comprised four dimensions, that is, attention, relevance, confidence, and satisfaction. Independent *t* tests were computed for evaluating the impacts of the AR-based science learning approach on the questionnaire ratings of the four dimensions. As described in Table 3, significant differences were confirmed with $t = 4.37$ ($p < .001$) for the attention dimension, $t = 2.92$ ($p < .01$) for the relevance dimension, $t = 2.80$ ($p < .01$) for the confidence dimension, and $t = 2.09$ ($p < .05$) for the satisfaction dimension.

For the attention dimension, the means and standard deviations were 4.16 and 0.52 for the experimental group, and 3.43 and 0.62 for the control group, indicating that the experimental group paid more attention to the learning activity than the control group did. Moreover, the AR-based science learning approach presented a large effect size in the attention dimension with $d = 1.28$ ($d > 0.80$). For the relevance dimension, the means were, respectively, 4.14 ($SD = 0.53$)

Table 1: The analysis of the ANCOVA on students' learning achievements

Group	*N*	*Mean*	*SD*	*Adjusted mean*	*Std.error*	*F*	η^2
Experimental group	23	87.83	9.15	87.01	2.56	5.03*	0.105
Control group	23	78.04	16.63	78.86	2.56		

$^*p < .05$.

Table 2: The t-test result of the two groups' motivations

Variable and source	*Group*	*n*	*Mean*	*SD*	*t*	*d*
Motivations	Experimental group	23	4.15	0.48	3.60***	1.06
	Control group	23	3.59	0.57		

$^{***}p < .001$.

Table 3: The t-test results of the four subscales of learning motivation for the two groups' motivations

Variable and source	*Group*	*n*	*Mean*	*SD*	*t*	*d*
Attention	Experimental group	23	4.16	0.52	4.37***	1.28
	Control group	23	3.43	0.62		
Relevance	Experimental group	23	4.14	0.53	2.92**	0.88
	Control group	23	3.67	0.54		
Confidence	Experimental group	23	4.10	0.46	2.80**	0.82
	Control group	23	3.60	0.73		
Satisfaction	Experimental group	23	4.23	0.61	2.09*	0.61
	Control group	23	3.80	0.79		

$^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$.

and 3.67 ($SD = 0.54$) for the experimental group and the control group, implying that the experimental group rated their perceptions of relevance to the learning activities higher than the control group did. The learning approach showed a large effect size in the relevance dimension with $d = 0.88$ ($d > 0.80$). With regard to the confidence dimension, the means and standard deviations were 4.10 and 0.46 for the experimental group, and 3.60 and 0.73 for the control group, indicating that the experimental group was more confident after the course than the control group, and the AR-based science learning approach had a large effect size in the confidence dimension ($d = 1.28$). As regards the satisfaction dimension, the means were 4.23 ($SD = 0.61$) and 3.80 ($SD = 0.79$) for the experimental group and the control group, respectively. It was found that the perceptions of satisfaction in the learning activities of the experimental group were higher than those perceptions of satisfaction within the control group. Moreover, the learning approach had a moderate effect size in the confidence dimension with $d = 0.61 (d > 0.5)$.

To sum up the effects of the learning approach on the students' learning motivations, the AR-based science learning approach had significant positive influences on the students' perceptions of their learning motivations in four dimensions, namely attention, relevance, confidence, and satisfaction.

Cognitive load

In this study, the survey of cognitive load was divided into two dimensions: "mental load" and "mental effort." The *t* tests were executed to probe the influences of the AR-based science learning approach on students' intrinsic and extraneous cognitive load.

In terms of the mental load dimension (as shown in Table 4), no significant difference was found in the two groups, with $t = -1.55$ ($p > .05$), indicating that there was no significant influence of the AR-based science learning approach on the students' intrinsic cognitive load. On the other hand, a significant difference was confirmed between the two groups' perceptions of mental effort, with $t = -2.07$ ($p < .05$). Furthermore, the means were, respectively, 1.98 ($SD = 0.71$) and 2.54 ($SD = 1.06$) for the experimental group and for the control group, illustrating that the students who learned with the AR-based science learning approach perceived lower extraneous cognitive load than those who learned with conventional multimedia science learning during the learning activity.

Interviews

To acquire more detailed understanding of the participants, six students in the experimental group (two each of the low-, medium-, and high-achieving students) participated in independent, semi-structured interviews conducted by one researcher of this study. From the analytical

Table 4: The t test result of the two groups' cognitive load levels

Variable and source	*Group*	*n*	*Mean*	*SD*	*t*	*d*
Mental load	Experimental group	23	1.89	0.63	−1.55	0.45
	Control group	23	2.32	1.19		
Mental effort	Experimental group	23	1.98	0.71	−2.07*	0.62
	Control group	23	2.54	1.06		

*$p < .05$.

results of the interview, it was found that the participants expressed some positions on the ARMTB approach, including "promoting learning interest," "presenting understandable materials," and "inspiring learning confidence."

From the position of "promoting learning interest," all of the students indicated that they were interested in the ARMTB learning activities. For example, one student revealed that, "Using AR technology makes learning more interesting." Another further mentioned that, "AR technology can be utilized in diverse subjects to enhance students' learning interests." From the "presenting understandable materials" perspective, five of the six participants indicated that students can easily comprehend the abstract concepts of the science books and reduce the barriers of the reading, via combining the AR technology and the textbook, and the interactions with the multimedia materials. For example, one student stated that, "We can understand more about the process of Terrain Formation." In terms of "inspiring learning confidence," four of the six students indicated that the ARMTB approach can improve their learning confidence and triggers their active learning. For instance, one student expressed that, "The effect of the AR is excellent. I think that my learning achievement will be improved by the AR-based learning."

Discussion and Conclusions

In this study, an AR-based learning system was designed to facilitate students' science reading. Moreover, plenty of multimedia materials were integrated into the implemented system based on the contiguity effect of multimedia instruction. To explore the effects of this approach on students' learning effectiveness, an experiment was conducted in an elementary school. The experimental results showed that this approach significantly promoted the students' learning achievements and motivations; moreover, their perceptions of extraneous cognitive load were significantly decreased during the learning activity.

The students learning with the ARMTB approach, which was developed based on the contiguity principle of multimedia learning, significantly reduced their extraneous cognitive load in comparison with the students learning with the conventional multimedia science method. By way of illustration, Leahy and Sweller (2016) described that extraneous cognitive load results from the instructional format and can be modified. In this study, the AR-based science learning system immediately displayed the related picture dynamically overlapping on the textbook while the students scanned the text. Such a result confirms what has been stated by Brunken et al. (2003) who illustrated that the contiguity effect can reduce extraneous cognitive load by simultaneously presenting corresponding pictures and words. Moreover, AR-based science learning systems can afford a kind of meaningful learning environment for helping students to acquire relevant information and to integrate it into their own coherent mental representations by offering the related 3D object dynamically overlapped on the textbook. Such a result complies with Mayer's (2014a) assertion that learners are actively involved in cognitive processing when constructing a coherent mental representation of their own experiences. As mentioned above, this can explain why the ARMTB approach can effectively reduce students' extraneous cognitive load in multimedia science learning activities, illustrating that adequately designing AR-based learning activities according to the contiguity principle of multimedia learning has the benefit of decreasing students' cognitive load.

As emotion plays a crucial role in multimedia learning (Knörzer et al., 2016), it is crucial to carefully implement the motivational design for stimulating and maintaining a more motivating learning environment. The ARMTB approach can effectively promote the students' learning motivations in terms of all four dimensions of "Attention," "Relevance," "Confidence," and "Satisfaction." Such a positive result may originate from the characteristics of AR, for example, augmenting students' interactions, engagement, and experiences (Yoon et al. 2017). This complies Cheng and Tsai's (2013) assertion, illustrating that AR has a positive influence on improving students' learning motivations. This result also echoes those of Wei et al. (2015), who integrated AR into the design of their study to promote students' learning motivation to work on a general technical creative design. Moreover, in Cheng's (2017) quantitative survey regarding AR book reading, the motivational factors of "Attention" and "Confidence" were deemed the crucial roles in students' perceived cognitive load, so as to predict their behavioral intentions. This study further proved the significant effect of the factor of "Relevance" on decreasing students' extraneous cognitive load in the AR-based learning environments. This corresponds to the view stated by the interviewed students, who considered the ARMTB approach as "presenting understandable materials" which can reduce the dilemma of reading. This could also be the reason why the ARMTB approach is of great benefit in terms of decreasing students' extraneous cognitive load.

The appropriate design of multimedia learning materials can enhance students' positive emotions and motivation and hence support the learning process (Heidig et al., 2015). This is one factor as to why the ARMTB approach may significantly improve students' learning achievements on science learning. This result is consistent with the findings described by Yoon et al. (2017), which stated that students' concept learning was significantly improved via interacting with the AR technology. Furthermore, Mayer (2014b) illustrated that motivational features can stimulate students to engage in learning processes so as to improve their learning achievement when they are not overloaded with processing. In this study, the ARMTB approach not only promoted students' learning motivations but also reduced their extraneous cognitive load, indicating a valuable reference for projecting a multimedia learning environment.

This study illustrated the potential advantages of utilizing AR technology in science reading. However, it should be noted that only a small-scale ARMTB learning activity was employed. In future research, it would be worth conducting a large-scale experiment or a quantitative survey for probing the influences of AR on science reading. Furthermore, with the advancements in media technologies, the ways to design a rich multimedia environment are becoming ever more diverse. The effects of multimedia learning could be evaluated by means of various advanced techniques in further research. Moreover, this study demonstrated the positive influence of AR on a multimedia learning situation based on the contiguity principle. More studies about the impact of different principles of multimedia learning on students' learning effectiveness could be investigated via multiplex learning approaches in the future.

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