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The Influence of Augmented Reality Embedding Cognitive Scaffolds on Elementary Students' Scientific Learning

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Abstract: Augmented Reality (AR) can enhance students' learning performance by visualizing abstract concepts. However, most AR applications in the classrooms just simply show virtual-real combined scenes without deeply integrated with learning materials. In that case, students would always have a lot of difficulties to construct knowledge by themselves. This study developed an AR application embedding cognitive scaffolds to help students better construct the scientific knowledge and explore the impact of those s cognitive scaffolds on students learning. A quasi-experimental method was used by dividing 42 students into three groups randomly, to investigate students' scientific achievements, learning experience and cognitive load. Students in experimental group 1 learned with AR without the support of cognitive scaffolds, and students in experimental group 2 learned with AR embedding cognitive scaffolds, while students in the control group learned with traditional method. Semi-structured interview was conducted after class. It is found that teaching with AR technology could significantly improve students' scientific achievements and learning experience. Compared with AR application without the support of cognitive scaffolds, AR with cognitive scaffolds has no significant impact on students' scientific achievements, learning experience, and cognitive load. Students in both experimental groups have better learning experience and lower cognitive load. The interview results revealed four advantages of AR technology: promoting students' cognition, having positive learning emotions, improving students' ability of hands-on and observation, convenient to use. And students' different attitudes towards the cognitive scaffolds were found in the interview, which might explain why the effects of cognitive scaffolds are not very significant.

Keywords: Augmented Reality, Science Education, Cognitive Scaffolds

1. Introduction

Augmented Reality (AR) has a powerful potential in education (Freeman, Adams Becker, & Cummins, 2017). As an extension of Virtual Reality (VR) technology, AR technology has the unique advantage, which can break the boundary between virtual space and real space(Milgram, Takemura, Utsumi, & Kishino, 1994). It brings new opportunities for education by helping students better understand abstract concepts, making up for the shortcomings of multimedia teaching in the past. In recent years, AR has been widely applied to science education, especially in improving students' spatial abilities, conceptual understanding and inquiry ability (Arici, Yildirim, Caliklar, & Yilmaz, 2019).

However, several research focuses on technology and ignores instructional design when applying AR in the classrooms, which causes many difficulties for students (De Jong & Van Joolingen, 1998). Therefore, some researchers have proposed scaffoldings to overcome these difficulties (Rutten, Joolingen, & Veen, 2012). A few studies showed that embedding cognitive scaffolds in AR is helpful(Wu, Hwang, Yang, & Chen, 2017). But according to the cognitive load theory, the scaffolds cannot help students' learning(Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012) even increase the cognitive load of students(İbili, 2019). Therefore, we developed an AR application integrated the supports of cognitive scaffoldings to explore the influence of the cognitive scaffolds in AR on students' scientific learning, and to investigate students' views on AR and cognitive scaffolds in it.

2. Literature Review

2.1 AR in Scientific Learning

Since the subject of science is mainly based on abstract content such as text symbols, students usually cannot really grasp some abstract concepts in scientific knowledge. AR provides a kind of ways to solve such difficulties. The character about combining virtual objects and real world makes it have a strong ability to establish situation. Therefore, AR could help students understand abstract concepts, enhance the learning experience, improve learning achievements and have a more positive attitude (Ibáñez & Delgado-Kloos, 2018), playing an important role in the field of science education.

Optical knowledge is one of the important concepts in science. In the traditional science class, previous studies revealed that students usually misunderstand the concepts in optics, such as: confusing the two concepts of sight and light(Andersson & Bach, 2005); confusing the color of the light itself with the color of the light reflected on the object. These misconceptions indicated that learners lack understanding of the presence of light, and the connection between colors of light and the colors of observed objects. In order to solve the above difficulties , researchers suggested using technology to help students understand the optics knowledge, such as simulation, game-based learning (Hvannberg, Law, & Halldorsdottir, 2018). A few researchers applied AR technology to teaching optical experiments for middle school students, such as convex imaging experiment, single-slit experiment and double-slit experiment (Cai, Chiang, & Wang, 2013; Niu, Xu, Cheng, & Cai, 2018; Wang, Zhang, Xue, & Cai, 2018), which confirmed the positive role of AR technology in assisting students to learn optics. It is necessary for educational researchers to take advantage of AR to develop relevant educational applications to help pupils' learning optics knowledge mentioned above.

2.2 Scaffolds in AR Learning Environments

When applying AR applications to a real teaching environment, three factors of content, technology, and pedagogy should be taken into the consideration comprehensively (Bidarra & Rusman, 2016). However, some studies of AR technology applying in the classrooms usually ignored instructional design well integrated with AR. For example, some studies showed that teaching with AR for inquiry activities had not improved the learning achievements (Kirschner, Sweller, & Clark, 2006). Therefore, after discussing and studying on these issues, some researchers proposed that scaffoldings maybe overcome these problems (Rutten et al., 2012). The scaffoldings are temporary supports and assistance provided by teachers or simulations. There are many types of scaffolds, such as cognitive, meta-cognitive, motivational, collaborative and knowledge-building scaffolds (Tsai & Huang, 2014). Cognitive scaffolds refer to the support, prompts, suggestions and assistance about the learning content, and strategies related to the problem solving. In recent years, researchers have considered to using computers to provide effective scaffolds, such as online teaching platforms, educational games (Hwang, Sung, Hung, Yang, & Huang, 2013). A few studies concluded that cognitive scaffolds in AR would support a better metacognitive process and reduce students' cognitive load (Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos, 2016; Wu et al., 2017).

However, some studies results argued that the embedding scaffolds into AR is not very helpful for students' learning. For example, Yoon's research indicated that some cognitive scaffolds may not be necessary to construct general concepts except for digital augmentation (Yoon et al., 2012). Although AR has a certain potential for reducing the cognitive load of students (Cheng, 2016), there are also some studies showed that too many elements (such as text, prompts, etc.) in the AR system would distract students' attention and increase students' cognitive load, by increasing extraneous cognitive load (İbili, 2019). In order to reduce cognitive load, it is necessary to remove interesting but irrelevant multimedia content and reduce the number of interactive elements (Mayer & Pilegard, 2014). It is not clear that how to integrate learning cognitive scaffolds with AR tools in the classrooms.

2.3 Research questions

The purpose of this study is to investigate the effects of AR applications and the cognitive scaffolds on students' performance in scientific learning. Further, we try to analyze the advantages and disadvantages of AR and cognitive scaffolds in it through interviewing teachers and students. The research questions of this research are as follows:

RQ1: Compared with traditional methods, can the AR learning method improve students' scientific achievements, learning experience, and reducing cognitive load?

RQ2: Compared with AR learning approach without the support of cognitive scaffolds, can the AR embedded cognitive scaffolds improve students' scientific achievements, learning experience, and reducing cognitive load further?

RQ3: What do students and teachers think about using AR integrated with cognitive scaffolds for learning/teaching?

3. Methods

3.1 Participants and Procedure

Because of COVID-19, the present study was mainly conducted through online teaching. A total of 42 sixth grade elementary school students participated in this experiment. They are from different provinces in China, including 22 boys and 21 girls, with an average age of 11 years (*SD* = 1.408). They were divided randomly into two experimental groups (EG) (n = 14 per group) and a control group (CG) (n = 14). All students did not learn the related scientific knowledge of optics before.

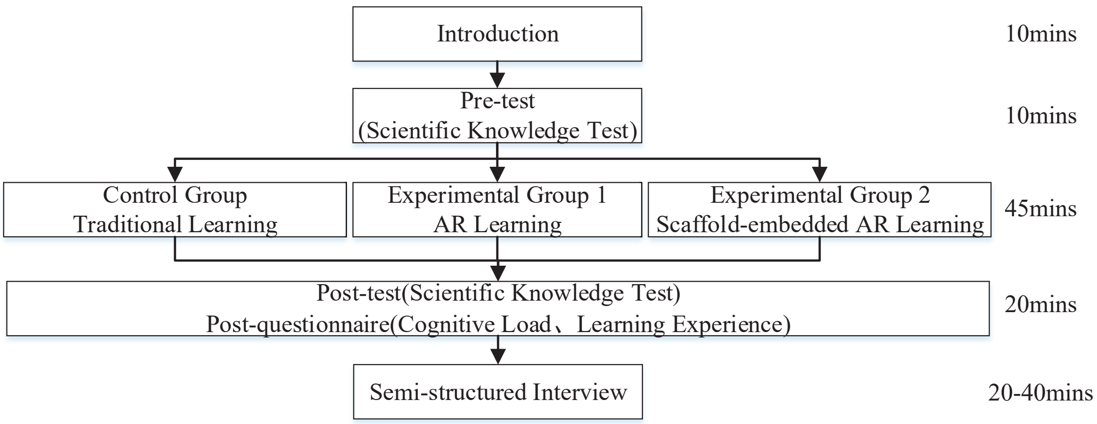

Figure 1. The experiment procedure of the present study.

The experimental procedure is presented in Figure 1. A quasi-experimental study design was used for this study. Before the course begins, there was a brief introduction concerning the basic concepts about light and the basic learning activities. After that, all groups of students were asked to take a pre-test to assess their prior knowledge of the scientific knowledge of the three primary colors of light. The classes were conducted through online video conferencing software. All participants used their parents' phone or tablet computer at home under the instruction of the teacher. The learning activities included situational introduction, inquiry, summary and practice, lasting for 45 minutes in total approximately. The students in the experimental group 1 learned with the AR application without cognitive scaffolds, while students in experimental group 2 learned with AR application integrated with cognitive scaffolds. On the other hand, students in the control group learned with traditional methods. The learning content and the teacher were same in all three groups except for experimental condition. After the learning activities, students were told to complete the post-test and post-questionnaires of cognitive load and learning experience. Finally, five students were recruited from two experimental groups to take part in a semi-structured interview to probe their opinions during learning with the AR application. The teacher was also interviewed.

3.2 Experimental Materials: AR applications

AR applications were developed by Unity3D and Vuforia on Windows 10 system, and then they were packaged into teaching software suitable for Android system. A total of two versions of AR applications were developed (Figure 2). Version one was used for experimental group 1 and there were no scaffoldings embedded into it; version two was used for experimental group 2 and cognitive scaffoldings were embedded into the AR system. Cognitive Scaffoldings in AR application included text highlighting, learning tips, feedback on student responses, etc. For example, we displayed and highlighted the specific text on the interface, and set up a "Learning tips" button. A learning cue for this scenario will be shown when students click on "Learning tips" button. Apart from the scaffoldings, the interface and activities in the two versions were identical.

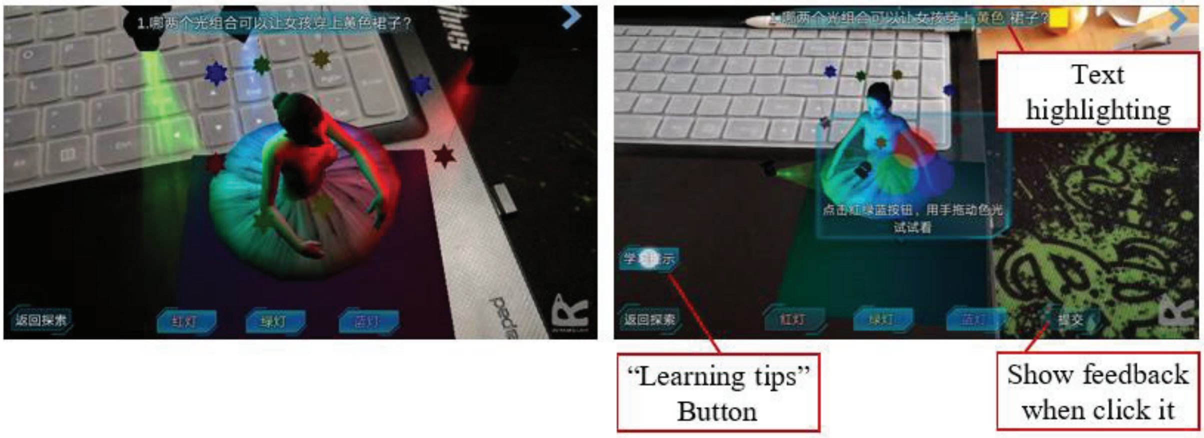

Figure 2. Two versions of AR applications. Left is version one (without scaffoldings), right is version two (with cognitive scaffoldings).

The AR applications were developed around the scientific concept of "the three primary colors of light" during the primary school period. There are 3 main scenes. The first scene is situational introduction. When scanning the special tracker cards called “marker”, a virtual dancing girl will show up. Students can observe the color of the stage lights and the color of the girl’s skirt, then the concept of the three primary colors of light were introduced; the second scene is about inquiry activity. Students can drag the light by finger and change the intensity of the light (click "+" or "-") to explore the mixing law of the three primary colors of light, and reach a conclusion finally; the third scene is about summary and practice activity. A total of three questions are proposed on the interface for students to practice and apply the mixing law of the three primary colors of light into real life.

3.3 Measuring Tools

Scientific knowledge test: The test was designed by a science teacher to evaluate the conceptual understanding and application of students’ scientific knowledge of the three primary colors of light. Both the pre-test and post-test had 10 items, including 6 multiple-choice items, 3 yes-or-no items and 1 open-ended question. The full score was 100 points. Its Cronbach’s α values was 0.73.

Cognitive load questionnaire: This questionnaire used a scale designed by Paas (Paas & Merriënboer, 1994). It consisted of two dimensions of mental load and mental effort. All items used a 9-point Likert rating scheme. In mental load dimension 1 meant "very easy", 9 meant "very difficult", and in mental effort dimension 1 meant "least effort" and 9 meant "maximum effort". Its Cronbach’s α was 0.74.

Learning experience questionnaire: This questionnaire was adopted from the scale developed by Stull (Stull, Fiorella, Gainer, & Mayer, 2018). It included three dimensions of learning motivation, interactive feeling and learning investment. There were 10 items in total, and the 7-point Likert scale was used. Higher scores indicated better learning experience. The Cronbach's α value of this questionnaire was 0.90, showing a high reliability.

The interview questions were modified from the questions developed by Hwang, Yang, Tsai, and Yang (Hwang, Yang, Tsai, & Yang, 2009). We used an audio recorder to record the interview data. The questions included but were not limited to the following:

Do you remember the parts of the AR class? What did you learn separately?
Which part of the course do you like best? Or what activities do you think are particularly interesting in this class? Why?
How is this class different from the science class you have taken before? why?
What are the advantages of AR application? What are the disadvantages?
What abilities did you improve in this class? Or what knowledge did you learn?
Do you like the tips and feedback in AR application? What do you think of them?

4. Results

4.1 Scientific Knowledge Test

A paired-sample *t*-test was conducted to analyze the difference between pre-test and post-test scientific knowledge scores of the three groups. The results are shown in Table 1. The post-test scores of the three groups of students were significantly higher than the pre-test scores. This means the students' performance has significant improvements after this science class.

Table 1. *The Paired t-Test results for Pre-Test and Post-Test Score Variables of Three Groups*

Group	*N*	*Pre-test*	*Post-test*	*MD*	*t*	*df*
CG	14	36.42（17.80）	66.07（18.10）	29.64	4.04^{**}	13
EG-1(AR)	14	29.64（19.16）	81.43（16.69）	51.78	8.78^{***}	
EG-2 (AR + scaffoldings)	14	37.5（17.18）	90.00（14.41）	52.50	9.23^{***}	

$^{**}p < .01$， $^{***}p < .001$

In order to compare the differences of the post-test scores between the three groups, ANCOVA was used by excluding the interference of the three groups' prior knowledge. The pre-test scores were used as covariate, and the post-test scores were used as a dependent variable. Before the analyze of ANCOVA, a homogeneity test was firstly performed. The assumptions of homogeneity of regression was satisfied (F (2,38) = 0.146, p> .05), then ANCOVA was performed. The results are shown in Table 2. It can be seen that excluding the effect of pre-test scores, students' post-test scores were significantly different between the three groups (F (2, 38) = 7.426, p = .002). The pairwise comparison results showed that the post-test scores of the students in the EG-1 (Adjusted M = 81.68, SD = 16.69) was significantly higher than the CG (Adjusted M = 65.97, SD = 18.10), indicating that teaching with AR was better than traditional methods significantly. In addition, although the post-test scores of EG-2 (Adjusted M = 89.84, SD = 14.41) were higher than those of EG-1 (Adjusted M = 81.68, SD = 16.69), there was no significant difference between the EG-1 and EG-2.

Table 2. *The ANCOVA Results of the Students' Scientific Knowledge Test*

Group	*N*	*M*（*SD*）	*Ad M*	*SE*	*F*	η^2	*Post-hoc*
CG	14	66.07（18.10）	65.97	4.46	7.42^{**}	.281	EG1>CG*
EG-1(AR)	14	81.43（16.69）	81.68	4.51			EG2>CG***
EG-2 (AR + scaffoldings)	14	90.00（14.41）	89.84	4.74			EG2>EG1

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

4.2 Cognitive Load

As shown in Table 3, ANOVA was conducted to examine the difference of cognitive load between three groups. In the dimension of mental effort, there was no significant difference among the three groups (F (2, 38) = 2.909, p> .05); in the dimension of mental load, the mean scores of the control group and the experimental group were 3.71 (SD = 1.72), 3.36 (SD = 2.49), 2.79 (SD = 1.62), and the difference among the three groups was not statistically significant (F (2,38) = 0.776, p > .05). It is worth noting that in the dimension of mental load, the values of the three groups were all lower than the average of 5, which meant that the students of the three groups all perceived a lower cognitive load in the learning activities.

Table 3. *The ANOVA Results of the Students' Cognitive Load*

Variable	Group	*N*	*M*（*SD*）	*SE*	*F*
Mental effort	CG	14	6.43（1.50）	0.40	2.909
	EG-1(AR)	14	7.21（2.32）	0.62	
	EG-2 (AR + scaffoldings)	14	8.07（1.43）	0.38	
Mental load	CG	14	3.71（1.72）	0.46	0.776
	EG-1(AR)	14	3.36（2.49）	0.66	
	EG-2 (AR + scaffoldings)	14	2.79（1.62）	0.43	

4.3 Learning Experience

ANOVA was utilized to compare the difference of learning experiences among the three groups. The results are shown in Table 4. There was significant difference between three groups in learning experience (F (2,38) = 4.688, p = .015). Specifically, the experimental group's learning experience was significantly higher than the control group. However, no significant difference was found between the two experimental groups. In addition, it is worth noting that students' learning experience scores in the experimental group reached almost full score (7 points), indicating that the students had a good learning experience in the process of learning with AR application.

Table 4. *The ANOVA Results of the Students' Learning Experience*

Group	*N*	*M*（*SD*）	*SE*	*F*	*Post-hoc*
CG	14	5.32（0.61）	0.16		EG1>CG*
EG-1(AR)	14	6.13（1.07）	0.28	4.688*	EG2>CG**
EG-2 (AR + scaffoldings)	14	6.22（0.82）	0.22		EG2>EG1

* p < .05， ** p < .01， *** p < .001

4.4 Interview Results

We used open-ended coding methods to code the interview data. The interview results are as follows.

4.4.1 AR Learning vs. Traditional learning

As shown in Table 5, when asked about the perception between learning with AR and traditional methods, students' answers revealed advantages of AR learning over traditional learning in the following four aspects: (1) cognitive, (2) ability, (3) affective, (4) usability.

For cognitive benefits, AR could promote the retention of scientific concepts, understanding and reflection of scientific concepts. Because AR can make objects stereoscopic and intuitive, which help students understand the concepts more clearly. As for ability, the AR application could involve students in the experiment, so it could improve their hands-on and observation skills, and develop their imagination to some extent. In addition, some students can connect the learning content with their real lives, such as S01, indicating that students could combine previous life experience and have a deeper construction of learning content. And for affective benefits, AR stimulated students' learning interest in science, improved learning motivation and self-efficacy. Last, for usability, because AR application is small and convenient, students would have more opportunity to do the science experiment. Some students may not have chance to do experiment by themselves in traditional science classrooms.

Table 5. *Examples of Students' Opinions Related to the Benefits of AR Application*

Number	Examples of students' opinions	Coding	
S01 S02	AR can help me learn scientific knowledge better. I learned that three colors can be mixed into many colors.	Retention	Cognition
S01 S02	The advantage is that it is particularly real, immersive, and can be hands-on. Knowledge is clearer than what I learned in school.	Understanding	
S03	Our teachers used to say that science and life are closely connected, but I couldn't feel that. Since listening to this lesson, I have felt they are really connected.	Reflection	
S02 S04	I think AR has improved my observation and hands-on skills. After do it by myself, I can solve more problems.	Hands-on & observation ability	Ability
S02 S01	It's easier to imagine something. In Tom and Jerry, there is an episode that the ice is frozen, they let the colorful light shine on the jelly and then the whole room is colorful!	Imagination	
S03 S04	I think AR is very interesting. There are no disadvantages. I hope it can be used in physics, chemistry, and biology classes. It can be very immersive.	Learning motivation & interest	Affective
S02	I'm more confident in solving scientific problems.	Self-efficacy	
S02 T01	AR is more convenient, you can adjust the strength of the light; and the effect is more obvious. The AR technology may be better and intuitive, and it is more convenient for children to observe.	Convenient	Usability
S04 S02	There aren't many opportunities for hands-on operation. Sometimes when doing experiments, it's not even my turn. Sometimes we can't go to the laboratory at all.	More operation opportunities	

4.4.2 AR with Cognitive Scaffoldings vs. AR without Scaffoldings

When asked about the cognitive scaffoldings embedded in the AR application, students' answers showed different attitudes towards the cognitive scaffoldings (Table 6). On the one hand, some comments revealed that the cognitive scaffoldings embedded in AR have positive cognitive and affective effects. On the other hand, some students said that cognitive scaffoldings were not necessary, and they don't need them in learning activities. This may explain why cognitive scaffoldings had no significant effect on students' learning performance, learning experience, and cognitive load in the quantitative results.

Table 6. *Examples of Students' Different Attitudes Towards Cognitive Scaffoldings*

Number	Examples of students' opinions	Coding	
S04 S03	It (scaffolding) helps me understand better. When I forget the key information, I can look at the "Learning tips" button, which helps me a lot.	Cognition	Positive
S05 S02	When I got it right, the box (feedback) gave me a sense of accomplishment. I think it's good and interesting, I can get a few more cues.	Affective	
S01	I don't need a prompt. The prompt is generally to tell you something, I don't think I need it.	Not necessary	Negative

4.4.3 Difficulties When Learning with AR

Apart from the advantages mentioned above, there are also some difficulties including usability and cognitive problems when learning with AR. Table 7 shows the difficulties when using AR. For usability, marker problems and health problems are two common challenges. And for cognitive difficulties, the teacher highlighted that AR might be too immersive for students to concentrated on teachers speaking.

Table 7. *Examples of Students' and Teacher's Responses about Difficulties When Using AR*

Number	Examples of students' opinions	Coding	
S01 S03 S04	The three colors of light are not very stable. The recognition picture is too small. I have problems when I recognize the card.	Marker problems	Usability
T01	It may not good for students' eyes when use it for a long time.	Health problems	
T01	The following situations often occur during the class: Some students have been addicted to AR's exploring activities, and they cannot hear me when I told them to do other things.	Distract attention	Cognition

5. Discussion and Conclusion

5.1 AR Can Improve Students' Scientific Achievements and Learning Experience Significantly.

One of the purposes of this study is to investigate whether the AR applications have positive effects on students' scientific achievements and learning experience compared with traditional teaching methods. The results of this study showed that using AR applications for teaching had significant positive effects on improving students' scientific knowledge achievements and learning experience. For scientific achievements, our results were consistent with the findings of Chang and Sahin. (Chang, Hsu, Wu, & Tsai, 2018; Sahin & Yilmaz, 2020). This may be caused by AR's special features, which is that AR can make the objects or phenomena that are difficult to visualize three-dimensional. Therefore, it was easier for students to understand complex and abstract concepts. In addition, learners could directly interact with the content and control the physical objects by themselves, which is more visualized than traditional method. This could explain why AR can improve students' scientific achievements and retain scientific knowledge. Further. we can also see words like "clear" and "intuitive" in the qualitative data, which verified this conclusion.

As to learning experience, this study indicated that teaching with AR applications can effectively improve students learning experience, which was consistent with the results of Diaz's research(Diaz, Hincapié, & Moreno, 2015). AR provided the opportunity to interact with virtual objects, bringing a different learning experience, which created a sense of realism for learners. Through the interview data, we can see that students' favorite part was the inquiry activities in AR. At this part, students had a high degree of freedom and had a lot of opportunities to interact with AR. The students' responses like "challenging", "I like interaction " indicated the positive experience that AR brought to them. Therefore, the inquiry activities in AR may be a main reason for improving students' learning experience.

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5.2 Cognitive Scaffoldings Embedded in AR Have No Significant Impact.

The second purpose of this study is to examine the effect of the cognitive scaffoldings embedded in AR applications on students' scientific achievements, learning experience, and cognitive load. The results showed that there was no significant difference between the two experimental groups in all dependent variables. Both EG-1 and EG-2 had high scientific achievements, learning experience and a low cognitive load. This was not consistent with Wu's research results (Wu et al., 2017). Wu developed an AR learning system based on mindtool to help students build their knowledge in science classes, showing that this kind of scaffolding can effectively improve students' learning performance. In his study, a low cognitive load was also found in both control group and experimental group during learning activities, and there was no significant difference between the two groups, which is consistent with our study.

This can be explained by the following reasons: First, some of the cognitive scaffoldings in this study may not be necessary for students to promote their learning. The qualitative data showed that there were differences attitudes towards cognitive scaffoldings embedded in AR, which was consistent with Yoon's research results(Yoon et al., 2012). Yoon explored the effect of integrating cognitive scaffolds to AR system, indicating that some cognitive scaffolds may not have been necessary to increase learning of general concepts except for digital augmentation, which was consistent with the qualitative results of this study. Another reason can be fact that the cognitive scaffolds provided in this study might not be well connected to the difficulties faced by students. In multimedia learning, cognitive and emotional design standards should be followed when developing an educational application, and giving special feedback and suggestions according to student problems are very necessary too. Therefore, it is worth discussing about how to design the scaffolds in AR in detail. In the future, researchers can explore the impact of the way in which scaffolds embedded when teaching with AR. For example, what's the effects of different kinds of scaffolds and the ways we used them. This would be helpful for us to know how to design the scaffolds in AR to help students learning in the future.

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