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Using Augmented Reality Technology to Learn Cube Expansion Diagram in Spatial Geometry of Elementary Mathematics

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***Abstract*—Spatial geometry has always been the key and difficult part in the curriculum of elementary mathematics. Compared with traditional teaching methods using, Augmented Reality (AR) technology shows its potential to teach spatial geometry through visualization, interaction and situation. This study focused on cube expansion diagram in spatial geometry and developed an AR learning tool based on inquiry for the course. The research aimed to examine the effectiveness of AR-assisted math lesson by designing and implementing two lessons in an elementary school. Two classes including 92 students in grade 5 participated in this study, and they were assigned to an experimental and a control group. This study adopted mixed methods methodology and utilized pre/post-tests, questionnaires and interviews. Results showed that students can general accept of using AR to learn spatial geometry, and AR-assisted teaching methods significantly improved students' learning outcome. It is also noticed that students' learning level affected their performance in AR-assisted math lessons.**

Keywords—augmented reality, elementary mathematics, spatial geometry, education

I. Introduction

Spatial geometry plays a significant role in elementary mathematics education, because it helps students cultivate space imagination and develop space thinking ability. According to the elementary mathematics curriculum standard in China, students should acquire preliminary space thinking ability and receive geometric education in the second period (grade 4 to 6). However, a number of primary school students are weak in three-dimensional spatial thinking and teachers need to spend a lot of time in helping them understand how to convert two-dimensional plane graphics into three-dimensional space.

Owning to the better learning experience, Virtual Reality (VR) and other technical tools can be strong drivers for future education[1]. As an extension of VR technology, Augmented Reality (AR) technology has attracted more and more attention in the field of education. By developing and creating AR-based teaching tool, virtual objects can be integrated with the real world. It breaks down the barriers between virtual space and real space, and helps students understand abstract geometric concepts better.

This study integrated AR technology into the elementary mathematics teaching of spatial geometry to examine the effectiveness of AR technology in improving primary students' learning outcome, and the suitability of this study was for large size of class.

II. Related Works

The teaching of spatial geometry at primary level is found to be difficult due to a lack of spatial geometry ability of primary school students who cannot understand parts of geometric knowledge, especially when it comes to transformation between two and three dimensions[2]. This requires researchers and practitioners to transform the traditional teaching method and adopt more visualized teaching strategy with a focus on students' practical operation during the learning process. However, the ongoing problem is that the traditional teaching elements impede the practical method to fulfill its superiority[3]. There are various ways to cultivate students' spatial concepts, and we should combine more teaching strategies[4].

The AR's role in accelerating educational innovation is the focus of worldwide researchers. Some researches focus on developing and designing teaching tools based on AR. These tools can present virtual objects in 3D and enhance learners' perception. For example, Bilinghurst used AR technology to create virtual scenes of a book and make reading more vivid than paper-based book[5]. Zarzuela used AR technology to develop and design virtual zoos where children can learn animal knowledge through scanning recognition images[6].

In addition to the development of AR tool, a number of studies focused on its application in teaching contexts, including some language disciplines. For instance, an AR-based Chinese phonetic symbol learning platform presented through animation, which significantly enhanced children's interest in learning Chinese phonetic symbols[7]. Word-memorizing app based on AR improved children's interest in language learning[8]. However, most of empirical studies focused on science or mathematics. Lin's research applied AR in physics teaching and used a physics engine to simulate physical mechanics experiments in real time, so that students could learn elastic collision and momentum better[9]. The experiment of material composition conducted by CAI proved that the AR simulation system can greatly promote the learning of chemistry courses[10]. Li, Shen, Wang and others conducted an experiment based on AR for probabilistic problems of mathematics, and confirmed that students' learning enthusiasm was significantly improved after using AR for learning[11]. Liu, Li and Cai also proved that AR could make students' learning gains better in the traditional mathematics class[12]. Cai, Liu, Yang and Liang found that the use of the AR application in the classroom could help students with higher self-efficacy to learn mathematics by adopting deep strategies[13]. This kind of AR research focused on the empirical exploration in subject teaching, confirming that AR-assisted teaching greatly improved students' learning outcome.

Nevertheless, there is a lack of study looking at the role of AR technology in assisting spatial geometry teaching, it is of conceptual value to use AR technology for spatial geometry's teaching. The cube expansion diagram is a plane figure obtained by cutting and unfolding the cube along edges. It fully utilizes the spatial geometry ability of students. In this study, a comparative experiment was conducted on the content of cube expansion diagram of spatial geometry to explore whether AR technology can significantly improve the students' math performance in the aspect of spatial geometry.

III. Development of Augmented Reality Teaching Tool

The cube expansion diagram application was developed by Unity3D + Vuforia on Windows 10. Firstly, we used 3dmax to complete the modeling and animation design of 11 kinds of cube expansion diagrams, which were subsequently imported into Unity3D to complete the construction of app interface and the compilation and implementation of functional code. Finally, we packaged the cube expansion diagrams app into a software package suitable for Android system for teaching.

The application includes two parts: the animation of cube expansion diagram (for teaching), and the typical exercises (for exercises). The first scene of teaching part includes the presentation of the AR recognition image and the combination of buttons and 3D models. The second scene is divided into four parts, according to the four categories of cube expansion diagram. The exercise part consists of three exercises with increasing difficulty. By using this application on tablets, learners can make the cube and its expansion diagram presented in 3D, and manually rotate the 3D model of the cube expansion diagram. In addition, 3D display scenes can also be provided for students to answer the following questions, so that they can observe and learn more intuitively, and explore the whole process of transforming from cube to cube expansion diagram.

This app is designed to help students to observe the model animation and manual interaction and understand the process intuitively with enhanced learning interest. Fig.1 shows interactive functions of the application, and Fig.2 presents the usage of the application in the study.

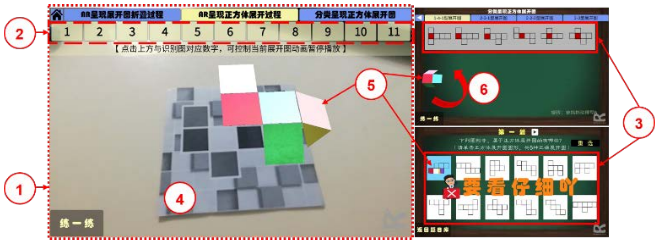

Fig. 1. The AR app of cube expansion diagram. ① AR interaction window, ② Animation control, ③ Interactive UI buttons, ④ AR Identification card, ⑤ 3D object, ⑥ Rotatation

Fig. 2. Animations and test of the AR app.

IV. Research Methods

A. Research Participants

As the 5th grade students were going to learn the knowledge of cube expansion diagram, they were suitable for this study. Two classes including 92 students in grade 5 participated in this study, and they were assigned to an experimental and a control group. The experimental group including 45 students used AR app, and teaching experiments were conducted around the course content of cube expansion diagram. The control group including 47 students used traditional teaching method to teach the same content TABLE I showed the demographic characteristics of participants and there was no significant difference regarding gender. The teaching tasks of the two classes were completed by the same teacher to control the variable of instructor.

TABLE I. Demographic characteristics of the participants.

	Experimental group	**Control group**	**Total**
Boys	24	23	47
Girls	21	24	45
Total	45	47	92

B. Research Hypothesis

- Hypothesis 1: Primary school students are willing to accept the teaching method based on AR.
- Hypothesis 2: Learners can obtain higher test scores and better learning effects through the method of AR-assisted teaching method than traditional teaching method.
- Hypothesis 3: The use of AR in spatial geometry of mathematics in primary school, has a more significant effect on students with low-achieving scores compared to those high-achieving.
- Hypothesis 4: AR-assisted teaching of spatial geometry has a positive impact on students' attitude,

motivation and self-efficacy in spatial geometry's learning.

C. Experimental process

The experiment consists of three stages as shown in Fig. 3. Before the experiment, a pre-test was implemented to assess all students' prior knowledge with a total of 10 questions and a full mark of 100. Based on the test scores, the two groups were compared if there was any significant difference regarding their prior knowledge of cube expansion diagram to ensure the relative consistency of the two groups. After the pre-test and questionnaires, the same teacher taught the same content to two groups respectively. AR-based teaching tool was used on the experimental group, while traditional multimedia learning methods which depended on PowerPoint and videos were used on the control group. After completing the teaching experiment, students were asked to complete the test paper and questionnaire. By comparing the test scores before and after the experiment, the effectiveness of AR technology used in spatial geometry of elementary mathematics can be examined.

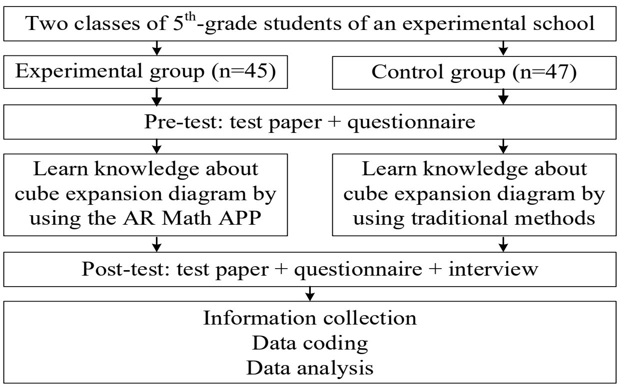

Fig. 3. Experimental procedure.

D. Data Collection Methods

1) Test paper: In this study, pre-test and post-test were designed to assess students' learning outcome. Both of them were designed after consulting mathematics teachers and integrating a large number of unit test papers. There are 10 questions in the pre-test and post-test, including 5 multiple-choice and 5 blank-filling questions. Each question is worth 10 points with a total of 100 points. Pre – test's and post-test's every point of knowledge is corresponding and the difficulty is the same.

2) Quesionnaires: Three types of scales were used in this study. The first scale was used to test students' perception of classroom teaching in the experimental group and the control group. Chu[14] 's scale of satisfaction with learning mode and Pearce[15]' s scale of learning activity experience were combined. Both scales adopted Likert scale with five options. What's more, Hwang[16]'s scale of cognitive load, which is divided into two dimensions of mental load and mental effort, was adopted. Secondly, a scale was used to test the transformation of student's learning attitude, learning motivation and self-efficacy through the experiment. Hwang[16]'s learning attitude scale, Hwang[16]'s learning motivation scale and Wang [17]'s self-efficacy scale were respectively adopted. Finally, in order to test the technology acceptability of augmented reality teaching method, Hwang[16]'s technology acceptability scale was adopted. The scale was divided into two dimensions, named "cognitive usefulness" and "cognitive ease of use".

3) Interview: An interview were used in this study. We randomly selected four students in the experimental class for a 10-minute interview, including two boys and two girls. The content of the interview mainly included suggestions for this class, feeling of AR-assisted teaching and cognition of the suitability to use AR-assisted tool in various disciplines. In addition, we asked interviewees to indicate their attitude of recommending AR-assisted teaching methods.

E. Data Analysis Methods

This study adopted mixed methods methodology by integrating quantitative and qualitative data. To carry on the quantitative analysis of the data obtained from the examination paper and the questionnaire, the objective comparison experiment result reveals the rule. The collected quantitative data were analyzed by SPSS19.0. Then, we carried out the qualitative research by recording classes, taking photos, taking lecture notes, and interviewing to make experimental results more reliable.

V. DATA ANALYSIS AND FINDINGS

A. Analysis of Technology Acceptance

In order to understand students' acceptance of AR-assisted teaching method, the technology acceptability of the experimental group was tested. The technology acceptability scale included two dimensions of 'cognitive usefulness' and 'cognitive ease of use', and questions were scored by using a Likert 5-point scale. First of all, according to the overall situation analysis, we found that students generally had a high degree of technology acceptance. Then, students were grouped based on academic performance. Students with scores from 90 to 100 were set as the high group, while those with scores below 90 were labeled as the low group. As shown in TABLE II. , the result of independent-sample t-test of technology acceptability showed statistically significant differences (T=2.214, P=0.039<0.05). Independent-sample t-test was conducted for two dimensions of "cognitive usefulness" and 'cognitive ease of use' separately, and the results showed that there was no significant difference in the aspect of 'cognitive usefulness', while there was a significant difference in 'cognitive ease of use' (T=2.301, p=0.033<0.05). It can be concluded that students with better academic performance could accept new technology easier than low-achieving counterparts, mainly displayed in the

TABLE II. Measurement results of technology acceptance.

Category	Group of high score (95-100)		Group of low score (below 90 points)		Differences（Sig）
	Mean	*Standard deviation*	*Mean*	*Standard deviation*	
Technology acceptance	4.700	0.403	4.125	0.802	0.039*
Cognitive Usefulness	4.733	0.458	4.000	0.894	0.086
Cognitive Easy-to-use	4.667	0.450	4.250	0.758	0.033*

dimension of 'cognitive ease of use'. The possible reason is that regardless of academic performance, students think that AR is helpful during the learning process, and students with strong learning abilities can accept new technology and follow the new teaching method quickly, while students with weak learning abilities need more time to adapt to the AR-assisted teaching method.

To understand learners' AR-assisted learning experience in-depth, we conducted interviews. It was found that:(a) all the four students thought that AR-assisted teaching method was interesting, targeting and clear compared with the traditional using lecture notes and PPT; (b) two suggestions were put forward as the AR learning tool's model identification stability was insufficient and students sometimes touched other apps without permission during the use of iPad; (c) three students believed that AR-assisted teaching method was helpful to illustrate abstract and complex concepts in science and math classes; (d) all of the four students suggested to implement AR-assisted teaching method at a larger scale, but when it came to teachers, three students mentioned that teachers might feel troublesome and unwilling to use it although they wanted to recommend the system to teachers.

B. Analysis of Classroom Feedback

The questionnaire implemented in the two groups includes three parts related to classroom feedback: students' satisfaction with the learning mode, the psychological experience of learning activities and students' cognitive load during the learning process. We conducted independent-samples t-test for the data of learning mode satisfaction, students' psychological experience of learning activities and students' cognitive load. TABLE III. showed that there was no statistically significant difference in learning mode satisfaction and cognitive load of the two groups. However, there was a significant difference between the experimental group and the control group in the perception of learning activities ($T=-0.659$, $P=0.028<0.05$). Students who used the AR learning tool were more engaged in the whole learning process and found it very interesting. Combining with observation of the video recording, as shown in Fig. 4, we further confirmed that students in the experimental group were more active and willing to participate in the activity, while the control group followed the traditional teaching method inclined to explore independently and were not active in the group inquiry session.

Fig. 4. Experiment scenes.

Therefore, we can draw a conclusion that the use of AR in teaching spatial geometry at the primary level led to positive classroom feedback by engaging students in immersive learning and active discussion.

C. Analysis of Learning Outcome

In terms of prior knowledge assessed by the pre-test in two groups, the average score of the experimental group was 59.34, and the control group was 59.57. TABLE IV. showed that the difference was not statistically significant, indicating that the variable of prior knowledge was controlled.

After the course, students completed the post-test and it was found that the score of the experimental group was 87.21 on average while the score of the control group was 79.09 on average. Independent-Samples t-test results of the two groups showed significant differences, as shown in TABLE V. To judge whether the test results were affected by students' pre-test, we used pre-test's score as the covariate and ran the

TABLE III. Measurement results of classroom feedback.

Category	**Experimental group**		**Control group**		**Differences（Sig）**
	Mean	***Standard deviation***	***Mean***	***Standard deviation***	
Learning mode satisfaction	4.607	0.488	4.477	0.792	0.365
Learning activity psychological experience	4.560	0.597	4.193	0.884	0.028*
cognitive load	4.429	1.039	4.261	1.291	0.511

TABLE IV. Independent t-test of students' pre-test scores in two groups.

	Levene's test for equality of variances		**t-test for equality of means**						
	F	***Sig.***	***t***	***df***	***Sig (2-tailed)***	***Mean difference***	***Std. error difference***	***95% Confidence interval of the difference***	
								Lower	***Upper***
Equal variances assumed	3.189	.078	.045	89	.964	.234	5.215	-10.129	10.596
Equal variances not assumed			.044	81.765	.965	.234	5.256	-10.223	10.690

TABLE V. Independent t-test of students' post-test scores in two groups.

	Levene's test for equality of variances		**t-test for equality of means**						
	F	***Sig.***	***t***	***df***	***Sig (2-tailed)***	***Mean difference***	***Std. error difference***	***95% Confidence interval of the difference***	
								Lower	***Upper***
Equal variances assumed	4.536	.036	-2.172	85	.033	-8.118	3.738	-15.551	-.686
Equal variances not assumed			-2.181	76.750	.032	-8.118	3.723	-15.532	-.705

TABLE VI. The ANCOVA test results for post-test of the two groups. Dependent variable: post-test scores.

Source	Sum of squares of type III	df	Mean square	F	Sig.
Correction model	8582.284	2	4291.142	19.116	.000
Intercept	44804.415	1	44804.415	199.594	.000
Teaching methods	1929.430	1	1929.430	8.595	.004
Pre-test score	7075.307	1	7075.307	31.519	.000
Deviation	18631.669	83	224.478		
Total	620000.000	86			
Total adjustment	27213.953	85			

TABLE VII. The analysis results of the relationship between the normal scores and the pre-test and post-test scores.

Group	Pre-test average	Post-test average	Gain average
95-100	66.11	87.22	21.11
90-94	58.39	89.44	31.06
84-89	38.57	81.43	42.86

TABLE VIII. The one-way ANCOVA test results for learning gain.

	quadratic sum	df	Mean square	F	Sig.
Between groups	2538.932	2	1269.466	3.284	.048
Within the group	15461.579	40	386.539		
Total	18000.512	42			

ANCOVA test, as shown in TABLE IV. We found that the pre-test score's associated probability was 0.000. Excluding the influence of pre-test score to post-test and only considering the variable of teaching method, the concomitant probability is 0.004. Both were less than the significance level of 0.05, which means although pre-test scores had a significant impact on students' post-test scores, teaching methods still had a significant impact on students' post-test scores after excluding the impact of pre-test scores. Therefore, it can be concluded that AR-assisted lesson of cube expansion diagram helped primary students achieve better learning performance than the traditional method.

In order to explore whether the average learning gain obtained by students using AR is affected by their academic performance, we selected students in the experimental group as samples and divided them into three groups. TABLE VII. showed the average learning gain of students in the three groups. Then, one-way ANCOVA test was conducted on the average learning gain of students according to the groups. According to TABLE VIII. the average academic performance had a significant impact on students' learning outcome ($F= 3.284$, $P=0.048<0.05$). That means that AR-assisted teaching method influenced students with low level of academic performance more than high-achieving ones.

D. Analysis of Learning Perception

This study explored students' mathematics learning attitudes in the experimental group before and after the course by utilizing a questionnaire. The questionnaire was mainly divided into three parts: learning attitude, learning motivation and self-efficacy. T-test of two paired samples was used for statistical analysis to analyze the effects of AR method on students' learning attitude, motivation and self-efficacy. The results showed that the associated probability of learning attitude in mathematics was 0.609, the associated probability of learning motivation was 0.825, and the associated probability of self-efficacy was 0.903, exceeding the significance coefficient of 0.05. Therefore, we believe that although AR-assisted teaching method can improve students' learning attitude, learning motivation and self-efficacy to some extent, there was no statistically significant difference. The limited time of experiment may be accountable for it, and we need long-term experiments to further explore the influence of AR method on students' learning perceptions.

VI. CONCLUSIONS AND PROSPECTS

A. Conclusions

Based on the research results obtained in this study, the following conclusions were drawn:(a) students generally accept the AR-assisted teaching method, because it engaged students in learning and discussion; (b) the application of AR technology in spatial geometry of elementary can significantly improve students' learning outcome; (c) students' academic performance affect AR-assisted learning. On the one hand, AR-assisted teaching method influenced students with low level of academic performance more than high-achieving ones. On the other hand, differences in learning level can also affect students' acceptance and mastery of the system. students with better academic performance could accept new technology easier than low-achieving counterparts; (d) AR-assisted teaching method can influence students' learning attitude, motivation and self-efficacy in learning mathematics to some extent, but there was no statistical significance.

B. Possible Suggestionss and Future Work

After the experiment, we put forward several suggestions of AR app design and application in future work. Firstly, the stability of AR identification card needs to be improved. In the teaching process, the models were sometimes unstable due to the light in the classroom. We can increase the contrast of the AR identification card to make it less affected by the light. Secondly, the application is inclined to display the model and its animation, which has shortcomings in teaching inquiry. It is possible to further enhance the exploration of the AR app by increasing virtual buttons. Finally, some redundancy exists in the functional interface with this app. The main manifestation of it is the overmuch button, which can be further improved by adjusting the display of the button to synchronize with the model or controlling the playback of the model animation through the model itself.

In terms of the teaching experiment, the exploratory part is not enough. We can create more independent inquiry content in the teaching process, so that students can make full use of the app to learn. In addition, the use of tablets should be strictly controlled and the rules should be clarified to avoid students wandering in class. As for experimental time, the periodicity of the experiment should be increased to conduct long-term empirical study. On the one hand, the number of post-test can be increased as immediate and delayed post-tests to examine both short-term and long-term effects of AR-assisted teaching method. On the other hand, through long-term demonstration, students immersed in long-term learning process can truly perceive the difference between AR-assisted and traditional teaching method and we can explore changes of students' learning attitude and motivation towards AR technology in mathematics learning.

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