The Effects of AR Learning Environment to Preschool Children's Numerical Cognition

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2022 International Conference on Advanced Learning Technologies (ICALT) | 978-1-6654-9519-6/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICALT55010.2022.00110

***Abstract*—Preschool children have difficulty learning and comprehending abstract concepts, and the cognition of numbers has always been the key to mathematical enlightenment for young children. Our research aims to help preschool children build their cognition of cardinal and ordinal numbers, comprehend simple logical relationships, and master simple digital addition. We developed an Augmented Reality learning tool based on theories related to number cognition and a theoretical framework of software design for preschool children. We also conducted a teaching experiment in a kindergarten, and interviewed the teachers of the kindergarten to learn about their attitudes towards the application of AR in preschool education. Through data analysis, interviews, and discussions, we conclude that (a) AR application can positively influence children's cognitive digital skills; (b) children have positive attitudes and positive evaluations toward AR application use, but there are some unavoidable problems in children's attention allocation; (c) proficiency in operating AR tools has a large impact on children's learning effects.**

Keywords—Augmented Reality, Preschool Children, Numerical Cognition

I. INTRODUCTION

The establishment of number concepts and the comprehension of number operations are important components in children's cognitive development. And the preschool period is a sensitive period for the development of mathematical skills ,a critical period for mathematical enlightenment. It is known that the cognitive process of preschool children is usually based on unintentional memory and image memory, supplemented by the children's natural re-creation of imagination. Therefore, for preschool children, figurative graphic perception is particularly important in the abstract mathematics learning process.

In recent years, the use of Augmented Reality(AR) in education has flourished. Many studies have investigated the effectiveness of using AR in education[1]. At the same time, AR in preschool education is also beginning to be used at an accelerated pace. Our research applied AR to preschool children's mathematical knowledge enlightenment, and tried to expand new ideas for teaching preschool children.

II. LITERATURE REVIEW

A. Numerical Cognition

It has been shown that cognitive ability has implications for human's living [2]. Numerical cognition is a central issue in the field of mathematical cognition research, a disposition and ability to use numbers and quantitative methods as a means of communicating, processing and interpreting information[3]. Most of the studies on the application of AR in mathematics education focused on the middle and high school to help students understand abstract conceptualization, such as the application of AR in teaching probability[4] and the impact of AR on students' learning methods and self-efficacy in mathematics[5].

Children develop considerably in mathematical knowledge and general cognitive ability during their time in primary school. Mathematics learning is supposed to develop reasoning and problem-solving[6]. Therefore, it is necessary to develop children's numerical cognitive skills at the preschool age to help them build their cognitive system.

A widely accepted model in academia divides the domain in which number cognition plays a key role into three components: number concepts, number operations, and applications of numbers and operations[7]. We designed a operational test with reference to the above model to examine changes in children's numerical cognitive ability after the teaching experiment, and then investigate the effects of AR use on preschoolers' numerical cognitive ability.

B. AR in Preschool Education

In recent years, the application of AR in preschool education is mainly about language and science, for example, an English learning software for preschoolers designed and developed based on AR[8]. And the form is mainly focused on cards,

* corresponding author. This work is supported by the National Natural Science Foundation of China (61977007).

978-1-6654-9519-6/22/$31.00 ©2022 IEEE
DOI 10.1109/ICALT55010.2022.00110

books, hardware devices, mobile applications, mostly using cameras to present virtual objects. Besides, there is a wide range of current scholarly interest in the impact of AR on preschoolers' learning process, including learning goals, learning competencies, barriers to learning, learning satisfaction, collaborative learning, learning support, etc. At the same time, the studies of the impact of AR applied on the learning process of children with physical and mental disabilities are also the current research hotspots.

There are numerous studies that confirm the advantages of AR when used in teaching. For example, a previous research demonstrated that AR can help students explore realistically in the real world[9]. Some researchers also believe that AR can facilitate the observation of events that are difficult to observe with the naked eye by displaying virtual elements alongside real objects[10] .At the same time, there are also some researchers who noticed the limitations of AR. Some studies have also pointed out that some students think AR is complicated, and they often encounter some operational problems when using it[11]. Without a well-designed interface and guidance for students, AR may be too complex for them to use[12].

In summary, there are different opinions on the application of AR in education, but it is undeniable that the application of AR in teaching has brought a promising development for education to a certain extent.

C. Studies on the Measurement of Children's Cognitive Ability

Cognitive ability tests usually include tests of general reasoning ability and tests of specific intellectual ability. For the measurement of overall cognitive ability in preschool, there are two well-known scales currently available. One is the Piaget Cognitive Development Scale (IPDT) compiled by Furth in 1970 based on Piaget's theory of children's cognitive development, which involves various domains such as conservation of cognitive structures, relationships, representations, classifications and laws, and mainly measures children's cognitive structures. The other is the third edition of the Wechsler Intelligence Scale for Preschoolers(2002), which divides tests into verbal and operational tests, with the number-related arithmetic tests testing children's ability to add and subtract numbers.

Based on the above research review, we developed a numerical cognitive ability measurement tool for preschool children, which is applicable to our research.

D. Research Questions

Our research aimed to develop an AR application for preschool children and investigate the effect of AR on preschool children's digital cognitive skills with the following research questions.

RQ1: Whether AR-supported interactive application has a more positive impact on preschoolers' numerical cognitive ability development compared to traditional teaching methods.

RQ2: Whether AR application could improve preschool children's learning interest.

RQ3: How do kindergarten teachers evaluate the teaching methods based on AR and what are their suggestions.

III. METHODS

A. Participants

A total of 28 sixth preschool students participated in the experiment,16 boys and 12 girls, with an average age of 54 months, who had not had systematic mathematical knowledge. They were divided randomly into an experimental group (EG) (n = 14) and a control group (CG) (n = 14).

B. Experimental Materials: AR application

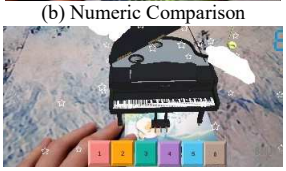
Referring to the educational game design framework[13], we designed the AR application. Its functions are shown in Fig.1. The first part is an interactive card game for recognizing numbers, scanning the cards of 0~9, there will be a process of transforming a figurative model into an abstract number symbol, which can help children construct the form of each number; after that, in order to help children understand the meaning of numbers and build up the concept of quantity, there will be a process of transforming the number model into a cartoon model, which symbols the quantity of the number. The second part is number sorting, a game that requires users to sort 0~9. The third part is simple addition, which allows users to add and subtract numbers in specific problem-solving scenarios. The fourth part is based on the STEAM education concept, which combines AR with music, allowing users to experience the charm of connecting numbers with tones.

The AR application was developed by Unity3D + Vuforia on Windows 10 system, and was packaged into a software suitable for Android.

(a) Recognition of Numbers

(b) Numeric Comparison

(c)Addition



(d) Numeric Music Box

Fig. 1. Application function display chart

C. Design of Teaching Activities

In accordance with the learning ability and cognitive habits of preschool children, we designed the teaching activities. The whole teaching process was divided into three parts: number recognition, numeric comparison and addition, with the experimental group (AR + teacher lecture) and the control group (PPT + teacher lecture).

1) Experimental group

Before the class, the 14 students in the experimental group were divided into groups of 2, using a tablet installed with the AR application.

At first, The teacher guided the students to place the number cards of 0-9 under the camera. The learning content includes visualization model, numerical model and quantitative model.

Then, the class moved to the stage of numeric comparison. Firstly, the teacher taught the comparison of numbers. Next, the teacher guided the children into the story situation, and introduces the numeric comparison part of the AR application, then demonstrated how to use it, helped students to explore the game process independently in groups, and finally explains the quantity comparison involved in the game.

The last part of the class is the learning of addition. Firstly, the teacher taught some simple addition problem, which are explained and shown by images and numerical signs. Next, the teacher demonstrated the use of AR application and explained the game's story situation, and then instructed the students to operate the AR application independently in groups.

2) Control group

The teaching activities of the control group were basically the same as those of the experimental group, however, the AR application operational part in the experimental group were changed to PPT demonstration.

D. Procedure

The experimental procedure is presented in Fig.2. The experimental hypothesis of our research is that interactive application supported by AR can help children learn mathematics better and improve their numerical cognitive skills more significantly than traditional teaching. The independent variable was "whether the AR application was used to teach ", the dependent variable was "the change in the numerical cognition ability of the children before and after the course (reflected by the comparison between the scores of the post-test and the pre-test)", and the control variables were the teacher, the duration of the lesson, the questions used in the pre-test and the post-test, and the test method.

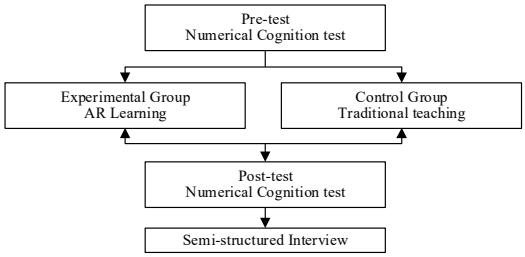


Fig. 2. Experiment flow chart

The 28 students were tested face-to-face at three aspects: cognition of cardinal and ordinal numbers, comprehension of simple logical relationships, and simple mathematical addition operations. The questions were presented visually in the form of language and physical expressions, which can be easily understood by preschool children. And the experimental group and the control group were taught separately.

At the end of the course, the 28 students were tested in the same way. However, the questions were changed compared to the previous test, but the degree of difficulty remained stable.

E. Instruments

1) Numerical Cognition Test

Referring to the studies of Ribeiro and Santos [14], Chernyak, Harris and Cordes [15] ,and Piaget's experimental study on number concepts, we designed the following operational test to achieve a measure of preschool children's number cognitive abilities. Children's performance in each session was quantified into specific scores for subsequent statistical analysis.

a) Step 1: Cognition of cardinal and ordinal numbers

- Test if children can fluently say 1~10 numbers in sequence and ask them some questions like "What is the number after 2?".
- According to Piaget's experimental study of cardinal and ordinal numbers, it is possible to determine whether children have the concept of cardinal and ordinal numbers by "changing the shape, size, space, and arrangement of a group of things that they have already counted, and then asking them whether they are still the original number". Therefore, in our research, we arranged some buttons in two rows of the same length, six in each row, and guided the child to understand that the number of buttons in each row was the same at first, and then, while the shape of one row remained the same, the shape of the other row was changed to a circle, asking the question "Are there as many buttons in both groups now? ".

b) Step 2: Quantity cognition and simple logical relationships comprehension (number comparison, class concept cognition)

- Introducing part: Put two black beads and eight white beads into a transparent container and let the child see them. Ask: "Let's play a game! Look, there are black and white beads inside the box. Now could you told me that are there more black beads or white beads?"
- Number Comparison part: Present two different numbers to the child, ask the subject which number is bigger.

c) Step 3: Addition operation

- Dictate to the child: Yesterday morning, your mom gave you 4 pieces of candy and in the afternoon, she gave you 4 pieces of candy; this morning, your mother gave you 1 piece of candy, and in the afternoon, she gave you 7 pieces of candy. Then ask them: "Did you eat the same amount of candy on both days? Or which day had more?"
- Addition test: Present simple addition equations to the child.

2) Outline of the interview

In order to understand the attitudes of the kindergarten teachers toward tablet teaching and the application of AR in kindergartens and their suggestions for improving the AR application developed in our research, we developed an interview outline as follow：

a) What do you think of the effectiveness of using AR software on tablets for teaching? What are the benefits and drawbacks?
b) Do you think tablet teaching can really make its way into kindergartens?
c) What do you think could be improved about the AR software used in this experiment?
d) What do you think could be improved about the identification cards used in this experiment?

IV. Results

A. Changes in digital cognitive ability

The differences between the pre-test and post-test numerical cognition tests of the two groups were analyzed using a paired-sample t-test. The results are shown in Table 1. The post-test scores of students in both groups were significantly higher than the pre-test scores. This indicates that the students' cognition of numbers and skills of operations have improved after this class.

TABLE I. The Paired t-Test results for Pre-Test and Post-Test Score Variables of Two Groups

Group	*N*	*Pre-test*	*Post-test*	*t*	*df*
Control Group	14	9.93（3.668）	12.43（3.390）	5.827^{***}	13
Experimental Group	14	10.79（3.620）	14.86（2.797）	5.647^{***}	13

Note: * $p < 0.05$， ** $p < 0.01$， *** $p < 0.001$

In order to compare the differences between the two groups of students' post-experimental numerical cognition assessment results and to exclude the interference of the pre-test results, ANCOVA was used with the pre-test scores as covariates. Before the analyze of ANCOVA, the chi-square test and parallelism test was firstly performed to assess whether the conditions of ANCONA were met. Levene chi-square $F = 1.717$, $p = 0.202 > 0.05$, and the assumption of homogeneity was satisfied. In the "group*pre-test score", $F = 2.386$, $p = 0.135 > 0.05$, so there was no interaction between the two and the assumption of parallelism was met. ANCONA was then conducted. The results showed that, excluding the effect of the pretest results, there was a significant difference in the students' post-experimental numerical cognitive abilities ($F = 6.360$, $p = 0.018$). Students in the experimental group ($M = 14.86$, $SD = 16.69$) had significantly better posttest results than the control group ($M = 12.43$, $SD = 18.10$), indicating that the use of AR contributed more to the improvement of preschoolers' numerical cognition than traditional methods.

B. Interview Results

In order to find out teachers' views on teaching with AR application, we conducted semi-structured interviews with two teachers from the kindergarten, asking them about their attitudes toward tablet teaching and the application of AR in kindergartens and their suggestions for improving the AR application developed in our study.

- **The effect of using AR in teaching.** First, more interactive software can effectively increase children's interest in learning, but it is also necessary to consider the convenience of software interaction. Secondly, the effectiveness of teaching can be influenced by the teacher, who requires both experience in communicating with preschoolers and experience in using AR.
- **Suggestions for using tablets in kindergarten.** It is important to think about whether the use of tablets can significantly reduce the burden of kindergarten teachers, the cost effectiveness of introducing tablets, and whether the tablets equipped with complete functions etc.
- **Suggestions for improvement of the AR application.** Educational software can contribute to the physical, cognitive, emotional, and linguistic development of young children, but it is necessary to consider the appropriate way of using it for young children. For instance, in our research, some of the children had difficulty to appear the 3D model on the cards due to the lack of precise control over the angle of the tablet camera.
- **Suggestions for the teaching method of using AR.** On the one hand, before students use the tablet, the regularity requirements should be declared (e.g., students can only use the tablet during the teaching session specified by the teacher) to ensure the normal classroom in order. On the other hand, in the classroom, students should be asked to listen to the teacher attentively before they begin to perform the operations on the tablets.

TABLE II. Excerpts from Teacher Interview

Excerpts from the interview	*Category*	*Code*
The operation of the software should be a little more simple and convenient. Children have to move the camera because the card have to be placed behind the tablet, so there exists some inconvenient place.	Convenience of software operation	The effect of using AR in teaching
In fact, this kind of software is really more interesting to children.	Improve interests	
In my opinion, to really enter the kindergarten, the tablet has to be more detailed and systematic, like the seewo whiteboard.	Tablets' functions	Suggestions for using tablets in kindergarten
The most basic is to reduce the burden of teachers, so it needs to show a large enough convenience.	Other suggestions	
The cards are very difficult for children to align.	Operation	Suggestions for improvement of the AR application
The words in the cards are useless for they are too small in relation to the cards and the children's literacy levels do not reach that high.	Cards	
Because the children are now all attracted to the iPad, so their minds will not think about what the teacher is talking about.	Class order	Suggestions for the teaching method of using AR.
We usually say all the rules clearly before, and then send the things to children to operate.	Other suggestions	

V. Discussion and Conclusion

A. Conclusion

Previous studies have confirmed the positive effects of AR Learning Environment on students' learning performance and motivation[1], but little attention has been paid to its effects on

students' cognitive abilities. In our research, through data analysis of changes in preschool children's numerical cognition, as well as observations of children's on-site performance and post-class interviews with teachers, we came up with the following findings.

First, interactive software supported by AR has a positive impact on preschool children's numerical cognitive development, which is largely consistent with the results of previous studies[16]. Based on the analysis and comparison of the pre-test and post-test results of the two groups of children, it could be found that the numerical cognitive skills of both groups of children improved, but the children in the experimental group showed significantly higher improvement in numerical cognitive skills than those who learned through traditional methods. We believe that such results are due to the interactive, visual, and 3D immersion features of AR[17], which largely match the cognitive level and learning habits of preschool children in terms of unintentional memory and image comprehension, and therefore achieve better learning results.

Second, preschool children usually held positive attitudes toward AR and showed extremely high interest in learning, but had some unavoidable problems in attention allocation, consistent with the cognitive tunnel effect. We noticed during the experiment that most children were highly interested in the learning content in the AR application and showed excitement, but at the same time, because the image content in the software was concurrent with the textual content of the teacher's lecture, some children's attention was fully focused on the screen of the tablet software and ignored the teacher's explanation of the content presented in the software, which might result in a short duration of improvement in digital cognitive ability and fading into oblivion.

Third, proficiency in manipulation had a greater impact on children's learning performance, in line with Lin et al.'s view of the limitations of augmented reality applications[10]. Through the observation of students in class and interviews with kindergarten teachers after the class, we found that some children were unable to adjust the camera to the right angle and also unable to use the auxiliary functions properly in the process of using AR application for the first time(due to unfamiliarity with the tablets and AR application), which had a certain degree of impact on their learning performance.

B. Future Work

Our research has demonstrated that the use of augmented reality technology is helpful in improving preschoolers' numerical cognition. Based on the present study, our future research could delve into the ways and interactive design details for AR educational applications adapted to preschoolers. In addition, this study only used pre-test and post-test to test preschoolers' numerical cognitive skills, and the number of participants in the quasi-experimental approach was small, so there may be a certain amount of serendipity. Future studies are expected to use technology to record students' response times or answer times and to increase the number of participants in the experiment.

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