Design and Development of Mobile Augmented Reality for Mathematical Experiments

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***Abstract*—In the information age, augmented reality has entered a period of rapid development, widely used in various fields. This paper is meant to firstly state the application status of AR in the field of education briefly and then summarize three types of teaching tools based on augmented reality: head-mounted AR, desktop AR and mobile AR. After comparing the three types of AR applications, taking the three views in the mathematics textbook of middle school as an example, the study designs and develops a mobile augmented reality software "Exploring the Three Views" to supplement class teaching, encouraging hands-on practice of students, with the aim to help students acquire the knowledge of three views, cultivate practical ability and improve spatial imagination ability.**

Keywords—Augmented Reality, Mobile Augmented Reality, Mathematics Experiment

I. INTRODUCTION

In the disciplines of physics and chemistry, experimental teaching is a very common teaching method. It not only helps students to form correct concepts, deepen understanding of knowledge, but also improves their practical ability [1]. In fact, there is also experimental teaching in mathematics. In order to help students construct a mathematical theory, test a mathematical hypothesis, or solve a mathematical problem, certain actual operation in mathematical teaching is necessary. Proper mathematical experiments can provide students with a learning environment where they are encouraged to learn actively and construct new cognitive structures, and lead students to practice on their own, explore independently, cooperate and exchange, cultivating their logical thinking and innovative thinking [2]. In traditional teaching, students usually master the knowledge through mass math exercises. Few mathematics experiments are applied because the experimental models are difficult to obtain and some experiments of thought cannot be realized. Thus, students cannot fully grasp the knowledge with few mathematics experiments.

In recent years, with the continuous development of curriculum resources construction and teaching reform, the application of various new technologies in teaching, such as big data, virtual reality, machine learning, etc., has been promoted. Augmented reality (AR) is developed based on virtual reality. The environment created by virtual reality is very close to reality, but this is precisely its shortcomings. The fully enclosed experience completely detaches the user from the real world, face-to-face communication and sharing between users being unavailable [3]. Besides, long-time wearing of the cumbersome head-mounted display causes discomfort such as dizziness and visual fatigue. To solve the problem, AR technology based on virtual reality is developed, which emphasizes the combination of real environment and virtual environment and its essence is to augment the reality. With the development of the information age, AR technology has been deeply applied to many areas such as medical treatment, education, military affairs, industry, and entertainment [4]. The application of AR in the field of education has greatly enriched the content and means of experimental teaching, and has significantly improved the quality and level of teaching in experimental courses [5].

Based on the literature research, this paper discusses the application status of AR in the field of education, and summarizes three types of teaching tools based on AR technology. Taking the three views of middle school mathematics stereoscopic content objects as an example, a mobile AR software-- Exploring the Three Views is designed and implemented to make an attempt to carry out experiments for mathematics relying on AR.

The rest of this paper is organized as followed: the second part combs some AR cases; the third part introduces the design and development process of "Exploring the Three Views"; the last part is the summary and prospect.

II. RELATED WORK

The Horizon Report is the annual result of a joint research by the New Media Consortium and the EDUCAUSE. The report highlights key trends, information technologies and key challenges that may have a major impact on US higher education in the next five years. In the 2005 Horizon Report, the “Augmented Reality” debuted in the field of scientific research and was listed as one of the six most promising technologies in the next few years. The 2011 Horizon report emphasizes that AR technology can present a powerful, contextual field learning experience in the real world [6].The 2016 Horizon Report states that AR helps students learn, placing learning content in a richer context closer to the real

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world [7].Through the use of AR technology, students can develop their own comprehension in the process of interacting with virtual objects, which is conducive to the divergence of students' thinking. Some unmanageable objects, a large amount of data, and non-static teaching processes in education can be presented to students in a visual form, so that students can easily understand and accept in the learning process. Augmented reality technology is expected to be widely used in 2 to 3 years [8].

From the perspective of theoretical research, the learning environment based on AR technology is consistent with the viewpoints of educational theory such as behavioral learning theory and situational learning theory. Behaviorism believes that learning is the connection between stimulus and response. AR technology can provide quick feedback on user input and has great potential for interactive teaching or assessment. Based on the perspective of situational learning theory, learning is a context-based activity. The learner completes the knowledge construction in the process of interaction with the situation and assimilate the new knowledge into the original knowledge structure. The seamless learning space created by the augmented reality technology can simulate the real learning situation and better present the learning content. The learner can obtain the real situation experience in this process, and then actively learn [9].

A. The Application of Augmented Reality in Education

AR first appears in the field of education in informal learning. With the maturity of technology, many researchers have made various attempts in mathematics, geography, physics and other fields, developed a series of AR applications, and designed many excellent cases which combines subject education with AR.

The AR learning resource developed by University of Washington research team Billinghurst is a children's book system called Magic Book, which makes the book content animated and superimposed on the book in the form of AR. The model seems to be connected to the real page, transforming traditional books from flat to three-dimensional, the reader does not need additional operations and instructions, and can see the three-dimensional animation superimposed on the book just by a specific AR display device [10].

Professor Kaufmann used the AR teaching aid named Construct 3D to present complex abstract spatial geometry in three-dimensional form. Using AR technology to cooperate with teachers and students, and to confirmed through experiments, observe and interact with 3D objects in the textbook, while enhancing the interest of teachers and students, also helps students improve their spatial imagination [11].The system provides basic elements such as points, lines, planes, and other simple elements. Teachers can easily interpret geometric transformations and their relationships in space, and students will better understand abstract and complex spatial concepts. However, the equipment required for the system is complicated, making the method less convenient to operate [12].

Hye Sun Lee and Jong Weon Lee designed a mathematics educational game aimed at kindergarten and elementary school students to help learners master the knowledge of addition in mathematics[13].They tend to get bored with traditional board games, and the improved chessboard with augmented reality technology, which constantly changes the chessboard content and the visual display of the 3D model helps to maintain the learner's interest in learning, and the child can enjoy an informative and intuitive board game based on augmented reality.

Li, Shen, Wang, Liu and Cai developed the coin-throwing augmented reality system by taking the classic coin-throwing experiment in junior high school mathematics "Frequency and Probability" as an example. The more times a coin is thrown, the closer the probability of its front and back is to 50%. Using AR technology, it can quickly and accurately record the statistical results of large sample times and obtain the real sense of “throwing” coins. The results of the study show that when using AR tools in mathematics teaching, students' learning enthusiasm is significantly improved [14].

Liu, Cheok, Mei-Ling, and Theng devised the AR teaching system between the nine planets of the solar system [15].The Nine Planetary Teaching Experiment System provides nine tagged cards representing different planets. During the learning process, the system will provide questions, and the learner will move the marker card representing the answer to the location specified by the system. AR can not only have the advantages of three-dimensional virtual objects, but also easy to operate, which can improve the learner's attention and learning effect compared to the simulation test with only text options [5].

The AR-based convex lens imaging aid developed by the Cai’s team simulates candles, convex lenses and fluorescent screens by using three different marker cards. When the camera captures the labeled cards, the 3D model of the candle, convex lens and fluorescent screen will be displayed on the screen. Teachers and students can change or move the markers in the real world. The equipment and experimental phenomena in the virtual world can be changed according to the convex lens imaging rules. The AR-based convex lens imaging teaching aid combines the virtual model with the real environment, allowing students to directly use both hands to perform experimental operations on their own desks, improving the degree of restoration of the scientific inquiry process and enhancing students' immersion and concentration [16].

B. Classification of AR Applications

The application of AR technology can provide educators with new teaching tools, stimulate students' motivation to learn new knowledge, and enable students to innovate in practice. The application of AR technology in education is a revolution in the field of education. It has evolved from a traditional “teaching as learning” learning method to a new learning method in which students acquire knowledge and skills through a new information environment and tools, it conforms to the educational concept of a new round of teaching reform and is conducive to the cultivation of students' core literacy. At present, the teaching tools based on AR technology are mainly divided into head-mounted AR applications, desktop AR applications, and mobile AR applications due to their different devices [17].

Head-mounted AR application. Head-mounted AR applications are generally smart glasses and smart helmets, belonging to wearable display devices, fixed to the human head [18]. When students use head-mounted AR devices to learn, they feel like they are in a real situation, which can bring students an immersive learning experience. Different from

virtual reality, students can still see the scene around them, virtual objects are superimposed in the real environment. Representative products of Head-mounted AR devices include Microsoft HoloLens, Meta 2 and Google Glasses, etc. However, head-mounted AR devices still have problems such as high cost, large weight and poor comfort.

Desktop AR application. A representative example of a desktop AR device is zSpace's all-in-one virtual reality machine, which allows users to control virtual objects as if they were real. In recent years, the zSpace Z300 has been widely used. The APP contains a number of basic courseware [19], which can not only be a teaching tool for teachers, but also provides abundant material resources for students and teachers. In addition, there are many desktop AR applications developed by researchers, mainly using a computer, plus a camera, to display 3D AR on the computer. Due to its large size, the desktop AR application device can only be used in a certain position because of its inconvenience, and the mature equipment is expensive, which is not suitable for promotion.

Mobile AR application. Mobile AR applications mainly use a combination of mobile devices (tablet computers, smart phone) and APP software, The method is to install APP software on mobile devices, then use the mobile device's camera to scan the mark, and overlay virtual objects on the real environment through mobile devices. APPs include A+ education, visual +AR, etc. When students use such APPs for learning, the learning process is more realistic and experiential, which enhances students' interest in learning knowledge [17] and optimizes classroom teaching effect. Due to the portability of mobile devices, students can use such applications for learning anywhere and at any time, but it requires high performance and energy consumption of mobile devices.

TABLE I. CLASSIFICATION OF AR APPLICATIONS.

Classification	*Representative products*	*insufficient*
Head-mounted AR	Microsoft HoloLens, Meta 2, Google Glasses, etc.	High cost, heavy weight, poor comfort, etc.
Desktop AR	zSpace	Large size, inconvenient to carry, expensive, etc.
Mobile AR	A+ education, visual +AR, etc.	High performance and energy requirements for mobile devices

III. DESIGN AND DEVELOPMENT OF MATHEMATICAL GEOMETRY EXPERIMENTS - "EXPLORING THE THREE VIEWS"

"Three views of objects" is the content of the second section of chapter 29 in the second volume of 9th grade in PEP Junior Middle School Mathematics Textbook. The teaching focus of this section is to deepen the understanding of the concept of three views from the perspective of projection, and to draw three views of simple geometric combinations. The difficulty of teaching is the sublimation of the understanding of the concept of three views and the ability to draw the three views of spatial geometry correctly.

In traditional teaching, teachers usually use the method of oral teaching, Without physical demonstration, students can't carry out real operation experience. They can only imagine the three-dimensional model of spatial geometry through two-dimensional images on books combined with logical reasoning. What should look like in three directions? At this stage of the students, from the perspective of students' cognitive level and ability, students are still in the stage of transition from image thinking to abstract thinking. The understanding of things remains on the surface, and the spatial imagination is insufficient. It is difficult to build a three-dimensional model in the mind, especially for those students with poor foundations. The spatial imagination ability plays an important role in the study of solid geometry in mathematics. Studies have shown that space skills can be improved through practice [20]. Therefore, we designed and developed a cube learning APP based on mobile AR - "Exploring the Three Views", to assist classroom teaching and help students master the knowledge of the three views and improve their spatial imagination.

A. Method

As for the developing environment, we chose Unity3D which is the most popular game engine on the market, and Vuforia as the AR platform, and Vuforia's image recognition was selected for experiment. For more accurate recognition, Fig. 1 is the target of the system.

Fig. 1. Image Target of this case.

B. Content Design

The main purpose of the APP is to assist classroom teaching and promote students' learning. Therefore, based on the exploratory mode and according to the points and difficulties in teaching, we designed the three-view program flow shown in figure 2, which is mainly divided into the main interface, the target recognition interface and the experimental learning interface.

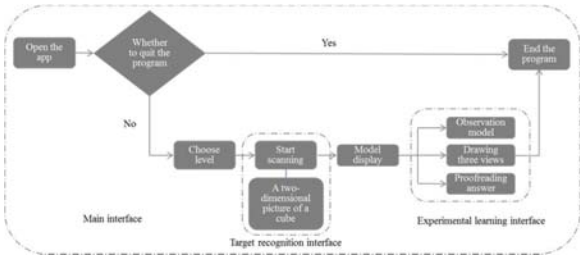

Fig. 2. "Exploring the Three Views" programming process.

- **Main Interface**

Figure 3 shows the main interface and menu interface of the software. As can be seen from the menu interface, the software contains three learning levels with different difficulty coefficients, and students can master the relevant

knowledge of the three views step by step from the simple to the difficult.

Fig. 3. Main interface and menu interface.

- **Target Recognition Interface**

Figure 4 shows the target recognition interface of the software. After entering one level, the camera of the mobile device is used to aim at the target card. After the camera captures the mark, the 3d cube model appears on the screen. Students can interact with the model through their fingers, including moving, rotating and scaling operations, so as to observe the model in an all-round way.

Fig. 4. Target recognition interface.

- **Experimental Learning Interface**

Figure 5 shows the experimental learning interface of the software. The experimental learning interface includes observing models, drawing three views and proofreading answers. After the model appears on the screen, students can observe the model structure from multiple angles, and then trigger the drawing board on the right side of the screen. According to the observation, students can practice drawing three views on the drawing board, and then check the system prompts to determine whether the drawn view is correct.

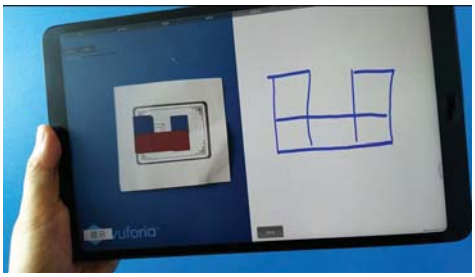

Fig. 5. Experimental learning interface.

IV. Conclusion

With the rapid development of virtual reality and AR, the application of AR in education has become more and more extensive, and a large number of achievements and cases have emerged. This paper first briefly introduces the application status of AR in various subject areas, and then summarizes the types of teaching tools currently developed based on AR technology, which is mainly divided into head-mounted AR, desktop AR and mobile AR. The three types have their own shortcomings. Mobile AR requires less hardware, easy to carry and more suitable for promotion in the field of education. Therefore, this study designs and develops a mobile AR software "Exploring the Three Views" based on AR technology to superimpose the teaching models into the real environment [21]. Besides, through natural interaction to interact with the model, it brings a real learning experience to students, which helps to promote students' interest and cultivate practical ability.

At the same time, this study also has its shortcomings. Firstly, the content should need further improvement. Secondly, extensive teaching practices are expected to be carried out. Therefore, our future plan is to go into the classroom and collect data to evaluate the effectiveness of the software.

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