Design and Implementation of an AR-Based Inquiry Courseware—Magnetic Field

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***Abstract*—Magnetic field is an important knowledge point in junior high school physics discipline. Due to its invisible feature, students require to concretely perceive the magnetic field through experiments. However, the traditional experiment has some defects such as inconvenient operation and insignificant effect. Computer simulation technologies can solve these problems by virtualizing them, but it currently has some shortcoming in terms of its experience and credibility. Based on augmented reality technology and the idea of inquiry learning, this paper designs and implements an AR courseware for magnetic field teaching. The experimental experience is enhanced by the fusion of virtual and real while visualizing the magnetic line. Finally, a preliminary application is carried out.**

Keywords—Augmented Reality, Inquiry Learning, Physical Experiment, Magnetic Field

I. Introduction

Experiment is an important method for people to cognize and transform the world, as well as an important part of teaching [1]. Professor Klaus Schwab, an educator, has suggested that teachers and students go to the laboratory and experience the process of scientific experiments, instead of teaching science in the classroom [2]. However, in the real environment, restrictions on equipment, venues, resources, etc. make some experiments difficult to carry out, thus students cannot obtain a satisfactory experience. With the development of computer technology, by which equipment, instruments and materials all have corresponding virtual modes in different situations, the virtualization of traditional experiments has become a new experimental teaching trend. For some invisible phenomena, computers can also be used to simulate the effects that traditional experiments can hardly present, such as struct of the molecule [3] and movement of the Solar System [4].

Magnetic field is the opening chapter of the knowledge "electricity and magnetism" in Chinese junior middle school physics textbook, which has a fundamental role for students to learn electromagnetic induction. In traditional classroom, iron filings, the objects to simulate magnetic lines, are easily adsorbed on both ends of the magnet. Therefore, it is difficult to operate and the magnetic field's directionality cannot be reflected vividly. Nowadays, many platforms and scholars have virtualized the magnetic field, and the experimental results are often positive. For example, the platform NOBOOK developed by Beijing Lebu Company allow users utilize mouse to drag the virtual magnet and move it in the designated area, and the computer presents the magnetic field around the magnet in the form of magnetic line [5]; María Blanca Ibáñez et al. employ Augmented Reality (AR) to Spanish high school magnetic field class. To simulate magnetic line, paper Maker was their option[6]. Cai et al. combined Kinect with AR technology to realize the natural interaction of the movement of the virtual magnet directly by hand, this apps allows users to observe the magnetic line in a real environment[7]. However, these experiments use only two channels-sight and hearing, ignoring the important feeling of attraction and repulsive force between the magnets in the magnetic field. Moreover, the magnetic field itself is invisible, and the magnetic line does not exist in reality. In these cases, the student cannot verify whether it is correct, and the authenticity of the virtual presentation will be suspected.

To handle shortcomings of traditional experiments and existing virtual experiments, this paper designs and develops an AR-based inquiry teaching courseware for junior high school magnetic field class, so as to improve the experience and credibility of virtual reality experiments. This courseware selects the real magnetic field experimental material, which preserves the tactile experience in the traditional experiment on the basis of vision and hearing. Therefore, the effects of the traditional experiment are retained while visualizing the magnetic field of permanent magnet (bar magnet & horseshoe magnet), and the learner can use the real magnetic needle to verify against the magnetic line.

The rest of this paper is organized in the following order: The second part briefly summarizes the theoretical basis of this paper and related work already carried out. The third part introduces in detail the design and implementation of the magnetic field AR courseware. The fourth part is a preliminary application, and the fifth part is the summary and outlook of this article.

II. Theoretical Basis

A. Inquiry Learning

Inquiry learning is a kind of student-centered independent learning, which aims to let students participate in the real process of scientific discovery [8]. At the beginning of the 20th century, American educator Dewey put forward the "child-centered" teaching method. He advocated that teaching should be carried out in accordance with setting questioning situations, identifying problems, putting forward hypotheses, and formulating and implementing solutions to problems. In this teaching mode, we can already see the idea of inquiry. In 1961, professor Schwab from the university of Chicago first put forward the idea of "inquiry-based learning" in his speech at Harvard University, which attracted widespread attention from the educational area. He believes that scientific conclusions only show what scientists see, yet the best way for students to learn science is to engage in the process of inquiry [9]. Since the 1980s, countries around the world generally began to pay attention to the cultivation of students' innovation ability, and more and more attention has been paid to inquiry-based learning, many countries have brought scientific inquiry into the curriculum objectives and content standards.

Inquiry learning is characterized by exploration, practice, process and openness. It is a question-driven, student-centered concept and emphasizes the effective combination of theory and practice, science and life. As a process activity, it has been carried out in various ways. Some scholars believe that questions, experience and reflection are the/ three basic elements of inquiry learning [10]. As Einstein said, "Asking a question is often more important than solving it", in inquiry-based learning, a good question plays an important role in stimulating students' inquiry motivation, determining inquiry goals and guiding inquiry actions. It points out the basic direction for learning. Embodied experience is the best way to verify problems, which emphasizes students' operational ability and encourages them to take the initiative to explore. In the experience, students can obtain the most authentic feeling, so as to keep continuous learning. Reflection in inquiry is the re-recognition and re-examination of students' thinking process and results. It is not only the collation and evaluation of the inquiry results, but also the thinking and pondering of on the problem, which runs through the whole process of inquiry.

Since the concept of inquiry learning was proposed, a large number of scholars have conducted empirical studies on inquiry learning in science education and verified its effectiveness. With the increasing popularity of virtual experiments, some scholars begin to transfer their attention to inquiry-based learning in virtual experiments. For example, Yuan and Li took the educational electroacoustic system as an example and created an open virtual learning platform to support students' independent exploration and learning [11]. Luo discussed the inquiry-based learning strategy in virtual experiments and carried out teaching practice. The results showed inquiry-based virtual experiment had a positive effect on teaching. Galan et al. affirmed the positive role of virtual experiments in exploratory learning and provided an integrated environment for automated experimental tasks to enrich the virtual laboratory ecosystem [12].

B. Augmented Reality

As we know, the real world is the space for human activities, while the virtual world is a computer-generated world. In general, these two worlds are separated [13]. Augmented reality technology realizes the connection between them, which integrates the virtual object with the real environment, thus user can interact with the virtual object in the real environment [14]. This feature makes the application of AR in education more widely. It can provide students with a variety of digital contents, so that knowledge would be presented in front of students in a concrete and specific way. At the same time, interaction between the real environment and nature is helpful to improve students' learning of presence and immersion.

Currently, AR has been widely used in education. For example, in 2013, Nedim Slijepcevic [15] developed an AR Teaching Aid for observing the phenomenon of the moon phase. By scanning corresponding marks with AR cameras, students can observe the four phases of lunar phase change in the form of 3D animation. In the educational game developed by Mitchlehan Media LLC to help children learn letters, when children align camera to point to the printed Flashcard, the 3D animals related to the letters will pop up on the screen. The sound of the pronunciation of the letter and animal's name will also appear when the virtual animal is clicked. However, different with ordinary teaching, experiment pays more attention to the real experience of students. In addition to vision and hearing, touch is also a very important learning path. Therefore, in AR experiments, how to balance the role of real and virtual, make the two parts complement each other and optimize the effect of the experiment, is the main problem that developers need to consider. Cai et al. [16] designed and developed a tablet-based AR app for learning probabilities. Students flipped a coin with two sides in a real-world situation, and then used the app on the tablet to identify and record the results (face up or face down). At the same time, a line graph of probability changes was automatically drawn on the tablet screen. In this experiment, the student's operation is not much different from the real experiment, and the function of the virtual part is mainly reflected in saving students time to record each result, so that students can focus on the experimental itself and better understand the concept of probability [17].

In the traditional magnetic field experiment, magnets and magnetic needles are cheap and easily available. Furthermore, the feeling of repulsive force and attraction between magnets, as well as the verification by magnetic needle, have auxiliary effects on students' understanding. The difficulty in teaching is mainly on the visualization of the magnetic field, which can be solved by computer. Therefore, with augmented reality technology, we can display the magnetic field distribution around the magnet in the virtual form, making the original abstract concept more specific and helping students understand. At the same time, real magnets and magnetic needles are chosen as experimental materials to retain the advantages of traditional experiments.

III. AR Courseware-Magnetic Field

Magnetic field is an invisible and untouchable 'object'. We can perceive it through experiments on magnetic phenomena to certify that it really exists. In order to conveniently and visually describe the magnetic field, people draw the arrangement of the magnetic needle in the magnetic field with arrow-shaped curves. These curves are called magnetic lines which are fictitious and do not exist in practice.

In the ninth-grade textbook of the junior high school physics of the People's Education Edition, the knowledge of the magnetic field is the first section of the chapter "Electrical and Magnetic", including three parts: magnetic phenomenon, magnetic field and the geomagnetic field. The textbook first takes the ancient Chinese compass as an example to introduce the common magnetic phenomenon in life and introduce the law of interaction between magnetic pole and magnetic pole. Then, starting from the two problems – "the role of force in magnetic phenomenon" and "how to describe the invisible magnetic field", the concepts of magnetic field and magnetic line are respectively introduced. Finally, there is a brief introduction to the geomagnetic field. The knowledge is well structured by this book. But considering that too much textual contents are likely to cause cognitive load on students, and the handheld tablet, as an electronic product, will do harm to students' eyesight for a long-time using, we focused on magnetic phenomena and magnetic fields instead of the geomagnetic field in the design process.

A. *Teaching Objectives of the Courseware*

Following the standard of junior high school physics textbook, we set the following teaching target:

- Understand simple magnetic phenomena and perceive the existence of magnetic field through experiments;
- Master the basic characteristics and drawing methods of magnetic lines;
- Learn how to generalize the law from physical phenomena and experiments through the process of operation, observation and summarization.

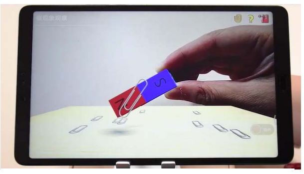
Based on this, this study suggests that the courseware should be set to three parts, including magnetic phenomenon experience, magnetic line observation, and the drawing practice of magnetic line.

B. *Content Design*

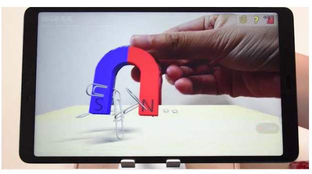
1) *Teaching Objectives of the Coursewar*

a) Instructional Design: Take the magnetic phenomenon of paper clips attracted by magnet as an example, Let the students experience the effects and summarize the rules from the observed results. Starting from the question of "Why the paper clips are concentrated at both ends of the magnet", students will learn the concept of "magnetic pole", and be aware of the existence of magnetic field by solving another question –"how does the magnet attract the paper clip on it without touching the paper clip? ".

b) Experiment Design: In the magnetic phenomenon experiment module, design details are as shown in Fig.1. At the bottom and the upper right corner of the screen are respectively a virtual table and "paper clips" and "operation tip" buttons, and the rest space is captured by the camera.



(a) A bar magnet attracts paper clips



(b) A horseshoe magnet attracts paper clips

Fig. 1. Experiment of magnets attracting paper clips.

In the experiment, when align the AR camera at the designated real magnet, the screen will display a virtual magnet that is consistent with the real magnet's size and spatial position in real time. In other words, when the real magnet is moved in the real world, the virtual magnet on the screen will also follow it. Every time user clicks the "drop paper clips" button, the system will randomly drop several paper clips on the table. When the magnet is close to the paper clip, the paper clip will be attracted to the magnet and concentrated on the poles of the magnet. Figure 1 also shows the results of respectively using bar magnet and horseshoe magnet to attract paper clips.

2) *Magnetic Line Observation*

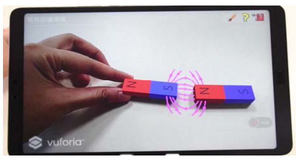
a) Instructional Design: Starting from the question of "how to describe the magnetic field distribution vividly", the concept of magnetic line is derived. Let the students observe the magnetic line around the magnet in different conditions, summarize and conclude the characteristics of magnetic line, and master the drawing method of magnetic line of the basic magnetic field.

b) Experiment Design: In the magnetic line observation experiment module, there is an "operation tip" button in the upper right corner of the interface, and the rest are the real scene captured by the camera. The experimental materials mainly include two real bar magnets and a real horseshoe magnet. When the AR camera aligns at the specified magnet, the screen will display a virtual magnet that is consistent with the real magnet size and spatial position in real time. In addition, the distribution of magnetic lines around the virtual magnet will be displayed. It mainly includes the following four situations:

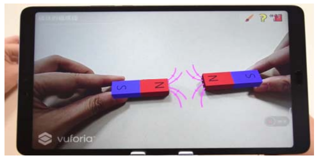
- The distribution of magnetic lines around a bar magnet, as shown in Figure 2(a);
- The distribution of magnetic lines around a horseshoe magnet, as shown in Figure 2(b);
- When the N pole of one bar magnet is close to the S pole of another one, the magnetic line distribution in the case of heterosexual attraction. As shown in Figure 2(c);
- When the same poles of the two bar magnets are opposite each other, the magnetic line distribution in the case of the homogeneity repulses. As shown in Figure 2 (d);

(a) around the bar magnet

(b) around the U magnet



(c) in the case of heterosexual attraction



(d) in the case of homosexual repulsive

Fig. 2. Basic magnetic field distribution.

Since the magnets are all real, in the experiment, students can also put a real magnetic needle or compass around the magnet to observe the rotation of the magnetic needle and test the magnetic line.

3) *Magnetic Line Drawing*

Timely practice is helpful for students to understand and master knowledge. In this part, students are provided with a drawing board tool. With the placement of four kinds of magnets as the background, students are required to draw the corresponding magnetic field distribution with magnetic line. During the drawing process, students are allowed to choose the color of the pen and modify the drawing. Figure 3 shows an example of the drawing results.

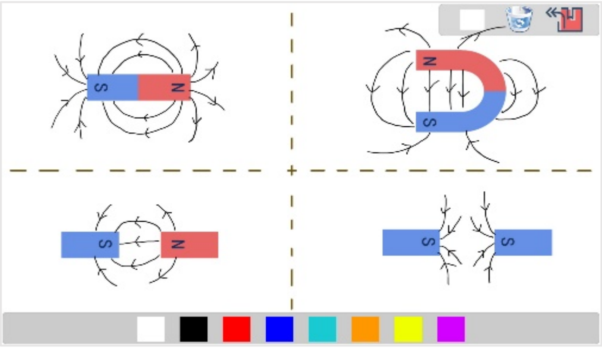


Fig. 3. The drawing results.

C. Key Technologies

1) Virtual-Real Fusion

The virtual-real fusion, utilizing Sensor technology, photoelectric display technology and computer graphics to blend computer-generated virtual objects with the real scenes of users, is an important technology to link the virtual world and the real world. It is also one of the pivotal means to realize this augmented reality system. In this study, key points to fuse virtual and reality are as follows:

a) Rendering target: We need to scan and identify the specified object to get a 3D model through the camera. This will be done by deploying the Vuforia SDK in the Unity 3d engine. Vuforia adopts a mark-based method, which utilizes object features, to realize the recognition of images and objects. Since the magnet is three-dimensional, we choose the method of object recognition. Install the software "Scanner" provided by Vuforia and print the scanning paper, then place the magnet in the specified scanning area to start scanning. The application provides realtime visual feedback of scanning progress and target quality, and builds a coordinate system that allows developers to build precisely aligned digital content for a good immersive experience. After this, the results are stored on the Vuforia database and mapped to the virtual magnet model in Unity. In this way, when the program is in operation, mobile camera scans to a specific real magnet, and the corresponding three-dimensional model can be obtained in the virtual world. In order to improve the recognition accuracy of the real magnet, the real magnet is packaged with paper wrapped by the camouflage pattern, and then recognized. As showed in Figure 4.

b) The virtual and real objects interact simultaneously: Since the size of the real magnet is fixed, when constructing the virtual magnet model, its length, width, and height ratio should be set to consistent with the real magnet, appropriate adjustments in Unity should be made to achieve the same size of the real and virtual magnets. Through the Vuforia's Object Target, the magnet model in the virtual space can be synchronized with the real magnet. In this way, the magnetic field distribution around the magnet can be seen from the virtual environment, and the learner can also feel the attraction repulsive force of the magnet. Therefore, the integration of the real and the virtual can be achieved to obtain a better learning experience.

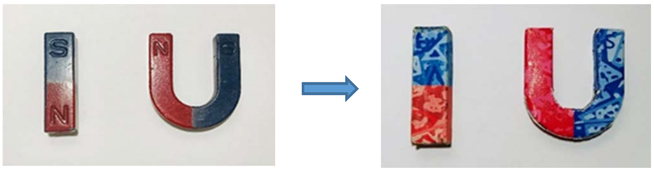


Fig. 4. Design of the magnet.

2) Virtual-Real Fusion

This research realizes the visualization of magnetic line through Bezier curve, which is the basic tool of computer graphics and image modeling. It can construct and edit the curve arbitrarily by controlling the starting point, the ending point, and two intermediate points [17]. Therefore, we only need to set the position of the four points, then can get a magnetic line by calculating them with the formula (1).

The mathematical expression of the third-order Bezier curve is:

$$B(t) = P_0(1-t)^3 + 3P_1 t(1-t)^2 + 3P_2 t^2(1-t) + P_3 t^3, \quad t \in [0,1] \tag{1}$$

In the formula, B(t) represents the position of the coordinate point at time t, P_0 represents the starting point, P_1 and P_2 represents the intermediate point, and P_3 represents the midpoint. The curve starts at P_0, goes to P_1, then goes from P_2 to P_4 ,but it usually doesn't go through P_1 or P_2, they're just there to provide direction. The spacing between P_0 and P_1 determines how long the curve is in the direction of P_2 before turning to P_3. The graphical representation is shown in Fig. 5.

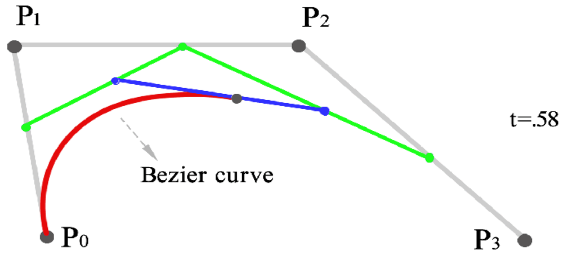


Fig. 5. The drawing results.

In this study, the points used to draw the Bezier curve (magnetic line) are calculated based on the relative position of the virtual magnet, which ensures that the position of the curve relative to the magnet is always correct. The figure below shows the effect of magnetic line around the bar magnet drawn with Bezier curves.

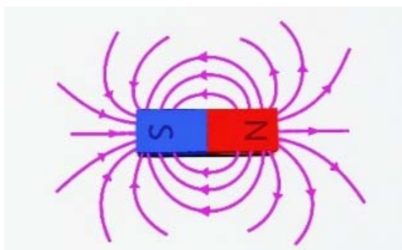


Fig. 6. Effect diagram of magnetic lines

IV. Application

In order to test the availability of courseware and learn of the students' attitude, three children (ages 14, 14, and 15) were invited for our initial application. They had studied the magnetic field but never experienced AR before. Firstly, an instructor gave a general introduction to the system. Then students studied with the magnetic line courseware on the tablet and experimental materials including three true magnets and a compass. At the same time, the instructor observed on the side and addressed students' problem when necessary. Finally, we communicated with the students.

The result of this test shows：

- In terms of content, through the verification of the magnetic needle, it can be considered that the magnetic field effect presented by the courseware is correct.
- In terms of usability, students thought that the operation was simple and easy to grasp. However, the tablet weighs heavily, which may cause an uncomfortable feeling after long-time using.
- Students hold a positive attitude on the AR experiment and hope to use it in other experiments.

In addition, we invited a teacher to experience. She believes that this approach is more convenient than using iron filings, and is more versatile than traditional virtual experiments. Finally, the teacher expressed her willingness to use the courseware in class.

V. CONCLUSION

Based on the augmented reality technology, this study designed and developed an inquiry courseware for magnetic field teaching, which can not only solve the traditional experiment's problems including inconvenient operation and insignificant effect, but also retains its advantages in experience and credibility. It visualizes the magnetic line and provides experimental operations with the feelings of virtual and real fusion. Students can explore the magnetic field knowledge through magnetic phenomenon experience and magnetic line observation, finally consolidate and sublimate knowledge in the magnetic line drawing part. During the design procedure of the courseware, students' independent inquiry ability is actively brought into play under the guidance of questions, and teachers mainly play a guiding and auxiliary role, which reflects the contemporary teaching concept of "students' subjectivity".

At the same time, this study also has its shortcomings. Firstly, for the development of magnetic field experiment, the courseware only provides students with several basic magnetic field magnetic line distribution, so the space for free exploration is limited. Besides, Bezier curve is a way to draw the magnetic line, there is still a certain gap in the accuracy of the magnetic line calculated by the scientific formula. Secondly, only a few students and teachers participated in our application, and extensive teaching practices have not been carried out to prove the effectiveness of the system.

In the following work, we will continue to optimize the courseware and hope to apply it to classroom teaching. In addition, the virtual-real fusion based experiment needs to comprehensively consider the design and combination of the virtual and real parts of the experiment, which is a new test for instructional designers. Therefore, which experiments are suitable for AR, and how to give full play to the advantages of AR experiments, are also the questions that need to be further explored in the future.

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