Design and Implementation of an Immersive Virtual Reality Biological Courseware—Miraculous Eyeball

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Design and Implementation of an Immersive Virtual Reality Biological Courseware— Miraculous eyeball

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Abstract. In recent years, immersive interactive technologies are becoming more and more mature. A large number of schools actively carry out virtual experimental teaching and establish virtual laboratories. As a kind of immersive interactive technology, virtual reality technology is attracting increasing attention in education. This paper describes the characteristics of immersive VR, hardware and software types, summarizes the different forms of VR used in teaching and discusses the principles of biological virtual experiment construction in other research. Taking the teaching content of 'structure of eyeball' in middle school biology textbook as a case, this research designs and develops a virtual experiment courseware - Miraculous eyeball. The research suggests that to construct outstanding teaching experiments of VR not only needs mature equipment and technologies but also requires a combination of decent teaching theories and tactics.

Keywords: Interactive learning; Virtual Reality; Immersive Courseware; Biological Experiment;

1 Introduction

Virtual reality is a digital environment integrated with vision, hearing and touching generated by computer technology. It combines with relevant science and technology and can be highly similar to the real environment within a certain range [1]. VR technology originated in the United States. As early as 1965, Ivan Sutherland proposed the basic idea that the VR system includes the interactive graphics display, force feedback device and voice prompt [2]. Then in 1966, Lincoln Studio in Massachusetts Institute of Technology officially started the research of HMD (head-mounted display). And in 1980, the first full-featured HMD was officially launched. After entering the 21st century, by applying robust 3D computing capabilities, rendering and data transmission, VR technology entered a completely new era. In 2013, Oculus released its HMD Oculus

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Rift, then HTC released its own HMD vive in 2015. With the participation of different giants, VR industry becomes much more matured. The media even regarded the year 2016 as "VR Year"[3]. “Virtual /Augmented Reality White Paper (2017)” released by the Chinese Academy of Information and Communication pointed out that in China, governments at all levels are actively promoting the development of virtual reality. VR has been listed in the "13th Five-Year" information planning, Internet plus and other major national documents. Till the end of 2016, nearly 20 provinces and cities began to develop the virtual reality industry.

Experiment is an important method of human cognizing and transforming the world. Laboratory experimentation plays an essential role in engineer and science education [4]. With the development of Educational Informatization and the innovation of new multimedia technologies, the employment of VR technology in teaching experiments has become popular. Various primary and secondary schools are actively setting up VR labs and carrying out VR teaching. It is generally believed that virtual experiments can provide learners with a flexible, open and independent learning environment and learning resources, thereby enhancing the teaching of science and engineering.

Numerous researches show that experimental teaching in the VR environment has the following advantages compared to the traditional classroom: 1. Can present the spatial relationship and the internal structure of the object perfectly 2. Can simulate a specific scene and perform dangerous experiments 3. Can save a considerable cost [5]. Thus, the immersive experience of teaching courseware and teaching environment has a high requirement. Existing virtual reality courseware designed for K-12 students is of varying quality, and most of them fail to achieve the desired effect. Many educators and manufacturers are actively exploring the best design method of VR courseware, considering how to integrate teaching in a better way.

Biological experiments are diverse in different environments. In a traditional classroom, when students engage in biological experiments, if some dangerous drugs need to be exposed, teachers should devote great efforts to arranging experiments in advance in order to prevent students from being in danger. Besides, sometimes microbiological structures cannot have the authentic feeling. But using VR technology can avoid many kinds of danger and enhance the sense of immersion and interaction [6]. This paper explores the application of VR in biology teaching under the premise of analyzing the application form of different virtual reality equipment in education. Taking the structure of the eyeball in the textbook of middle school as an example, this research designs and implements a VR-based biology courseware- Miraculous eyeball in order to make a probable attempt at immersive biological teaching.

The rest of this paper will be organized in the following order: The second part summarizes the different types of VR devices and explores their application in teaching. The third part introduces the design process of the biological teaching courseware. The last part is the summary and prospect of this article.

2 Immersive Virtual Reality Equipment and Analysis of its Educational Application

VR has three major characteristics: Imagination, Immersion, Interaction. And according to different standards, VR systems have different categories, which usually be divided into the following three categories: 1) desktop virtual reality system (Desktop VR), this system is mainly using graphics workstations and monitors, a virtual scene is created and participants use peripherals such as a mouse and keyboard to interact. 2) Distributed VR, it is based on a networked virtual environment in which multiple users or virtual environments at different physical environments are connected each other, another circumstance is that multiple users are participating in the same VR environment, people interact and share information with other users through the computer. 3) Immersive VR, which is based on head-mounted devices and projection devices. It can provide users with the same scene in two different viewing angles so as to achieve an immersive 3D experience.

The diversity of VR technologies offers a variety of options for different types of instructional content. Currently, immersive VR teaching based on HMD is the mainstream solution in teaching. For biology class, immersive HMD can provide realistic interact and vivid demonstration. To a certain extent, it can also save manpower and material costs. Therefore, immersive VR is the main topic of this article, and immersive VR headset is selected to design the courseware in this research.

2.1 The Feature and Types of Immersive VR

Immersive VR provides a fully immersive experience for the participant, gives users a feeling of being in the real world. It encloses the visual, audible, and other senses of participants in a pre-designed virtual reality space which mixes sound, location tracker, data glove, and other hand-held input devices to give participants an immersive, focused experience. Autonomy, presence and interactivity have constituted its three core characteristics [7]. At present, HMD (head-mounted display) and projection VR system are the most common Immersive VR device.

2.1.1 HMD (head-mounted display) VR System

- *Mobile VR headset*

In 2014, Google's I/O Developer Conference released a seemingly "chilly" cardboard box, but it had become the biggest surprise in this session. Google promotes VR into the ordinary mobile phone through this cheap approach, and mobile VR concept began to emerge. Mobile VR, as its' name implies, is a VR box with a pair of convex lenses attaching a mobile device based on the principle of binocular parallax. In order to bring immersive experience, the corresponding pictures of two eyeballs display on the two sides of mobile phone. Mobile VR has portable, cheap and other advantages. it brings many people who have no conditions to experience VR a viable way to feel it. By the end of 2017, the cardboard application download volume in the Google Play Store has exceeded 10 million. After that, many manufacturers also released their own "cardboard", such as Storm Mirror, Xiaomi VR box, Samsung gearvr and so on.

However, due to mobile device limitations such as phone's inherent low-resolution and CPU/GPU weakness, the feeling of dizziness may be occurring when experience VR, and only through the gyroscope 360-degree operation walk and interact in space is impossible. In education, the applications of cardboard mainly focus on users' experience. For example, Nival continuous release several cardboard-based educational games such as Inmind and Incell. It is worth mentioning that Incell provides a scientific strategy for players to experience the microscopic world of human cells and to learn how to prevent the invasion of viruses in advance.

- *All-in-one VR headset.*

All-in-one device is a VR headset with an independent processor. It possesses separate operation, input and output functions. Though the configuration is not as strong as the PC VR headset, All-in-one VR has no connection constraints. And it has a better experience compared to mobile VR since the higher degree of freedom. With the maturity of inside-out, slam and other technologies, all-in-one VR device also ushered in its spring. In the second half of 2017, oculus go, released by Facebook, supports three-dimensional head tracking (3DOF) with the "best optical system" and "wide field of vision". Fast switching technology, high visual clarity, making its experience closer to the pc VR. Its presence brings all-in-one VR machine an unlimited future.

In China, Pico and IdeaLens are two major companies providing equipment for STEM education in primary and secondary schools and they have established a large number of high-quality teaching resources through cooperation with various VR education companies. At present, teaching applications of all-in-one headset are also mainly for display, such as VR museums.

- *PC VR Headset.*

For the perspective of demand, human-computer interaction becomes the core feature of VR compared to other inherent attributes of mobile phones and all-in-one devices. On the other hand, the VR terminal may degenerate into just a head-mounted TV/mobile phone without interaction. The use of outside-in technology in pc VR is a good solution to the problem of interaction. PC VR refers to VR display device with the high-performance computer. With sensing capabilities and interactive features, its data operations, image transmission, etc. completed by PC, has high quality [8]. PS VR, vive and oculus rift are the three most popular PC VR products at present.

In educational field, PC VR covers a wide range, including virtual tour, presentation, skill training and so on [9]. For instance, a group of Irish students rebuilt historic sites in OpenSim (a 3D environment) and ramble freely in it through the Oculus Rift headset. With the help of MissionV, this VR project provided Irish students with portable tools to build VR scenes.

2.1.2 Projection virtual reality system

In 1995, students at the University of Illinois established a three-sided projection room, in the middle of the it, users wear stereoscopic liquid crystal shutter glasses to watch VR movies. Based on this, they developed the CAVE (Cave Automatic Virtual Environment) which we can see in the fig1. CAVE is a projection-based immersive VR

device that features high resolution, immersive and interactive characters. For Immersive experience and rich scientific research achievements, CAVE played a significant role in promoting modern virtual reality technology to the public [10]. In China, The VR-PLATFORM CAVE system developed by Vistandard has made a lot of innovations in military simulation, biomedicine, virtual disassembly, geology and topography education. Compared to HMD, the cave system is very expensive but more suitable for large class.

Fig. 1. Mobile VR, All-in-on VR, PC VR and CAVE System

For the four distinct categories of VR, we conducted a comparative evaluation of them in terms of immersion, interactivity, imagination, price and applicable class size and got the following results.

Table1. Comparison of different VR

Comparison of different VR	imagination	immersion	interaction	price	portability	Class Size
Mobile VR Headset	low	low	simple Interaction	low	Portable	medium size class (To some extent, it is not suitable for classroom teaching for the diversity of different mobiles)
All-in-one VR Headset	medium	medium	simple Interaction	medium	Portable	large class
PC VR Headset	high	ultra	Rich Interaction	high	cumbersome	small class (each student owns device)、Large class(3-5 students per device)
Cave Automatic VR	extreme	medium	Lack of interaction	ultra	Cannot carry	small class(cave system)、large class(9D movie)

2.2 Review of Educational Experiments of Immersive VR and Discussion of Its Construction principle

As early as 1993, China University of Science and Technology was engaged in the research and development of campus virtual teaching experiment software. Two years

later, the "WUJI Computer Simulation Experiment" system became the first VR learning software in the world, and many schools used this software for teaching [11]. Currently, there are also some web-based virtual engineering experiments developing by some companies such as Nobook. These Desktop-VR to some extent allow students to DIY and stimulate students' imagination. But the downside is low immersion and less interaction. Many researchers have been exploring the immersive VR teaching methods and theories based on HMD. Rong Cui has proposed five-point design principles of CAI Courseware based on VR. He believes that the difference between the construction of VR teaching resources and traditional teaching resources is the integration of student-centred concept and the idea of cultivating self-exploration capabilities [12]. Gao Y.D. has corresponding research on the construction of VR virtual venues. He proposed the principles and strategies of constructing VR learning resources, including the advance of hardware selection, the elaboration of contents, the logical layout of structures, and the specialization of venue layout [8]. In the field of educational game, Wang, C, X. et al. of Peking University Argue that VR/AR educational games and applications mainly have the following theoretical basis: situated learning theory, embodied cognition theory, flow theory and cooperative learning theory [13]. Currently, experiment courseware based on immersive VR is mainly focused on engineering subjects. In biology, there are also some practices.

- Biological Experiment

Biological experiments include basic biology, biochemistry, biotechnology engineering, physiological anatomy, cell biology, molecular biology and microbiology and other experimental courses [14]. From another perspective, the preparation of biological experiments and the experimental process are time-consuming. In some more experiments, If the operation fails, students can not repeat the experiment again. Therefore, the use of VR can effectively save time and costs.

Jie Xu of Qingdao Experimental High School produced VR courseware "gene expression" which clearly expresses gene transcription and translation from curriculum introduction to classroom reflection through "Brain Tour", "Cell Structure", "Transcription" and "Translation" four scenes. Experiments show that VR can mainly reduce the cognitive load of students, convert abstract knowledge to figurative forms. And by interacting with the VR environment, students' idea can be inspired [15].

Chen, J, J. of Central China Normal University designed and developed the "Bacillus subtilis isolation and culture" experiment based on HTC VIVE (pc headset). Except for the characteristics of bacillus morphological, students can understand the basic process and precautions of separating the target microorganism from the complicated environment. His combination of narrative theory in VR broadens courseware's perspective, attracts more attention and increases immersion in VR experiments [16].

As for the combination of VR and Biopsychology, Song, H, M., et al. trained 116 pilots by self-designed VR levitation and relaxation feedback system. The experiment proves that the new biofeedback technology with VR technology as a carrier has an obvious effect on learners compared to traditional psychology technology and levitation technology [17].

More research shows that the principles below need to be followed in the production of VR courseware in biology:

1. Need to be different from the traditional multimedia courseware, the models should have an appropriate volume for a better demonstration and research
2. Need to construct reasonable scene in line with the corresponding learners' age and psychological characteristics
3. Need to combine the appropriate teaching theory, such as the embodied learning, spiral learning theory and so on
4. Need to control the learning time, it should be noted that VR courseware cannot completely replace the classroom, so the instructional design should be closely integrated into it

3 VR Courseware-Miraculous eyeball

The structure of human eyeball is derived from the first section of chapter IV in PEP (People's Education Press) Junior High School Biology Textbook Volume 7, and title of this section is "Body's perception of the external environment". This section consists of three parts: the basic function and structure of the human eye, the process of visual formation, the causes of myopia and its prevention.

The textbook introduces the basic structure and function of human eyeball through the principle of camera imaging. Then by illustrating a vivid example that cat's pupil can self-regulate in the environment of different brightness, it shows that the human eyeball can also be self-adjusted according to different environments. Finally, causes of myopia and principles to adjust will be introduced. The knowledge is well-structured by this book.

However, as for the textbook, it only shows a simple two-dimensional structure of eyes. Students can only construct the specific structure and details of the eyeball by imagining. Therefore, it is hard to explore the structure of the eyeball and the visual principle through traditional textbooks. If we employ VR technology, a lifelike eyeball can be created, and learners can freely scale, move, rotate it. By this way, not only can immersive sense be brought but also students' learning motivation can be stimulated.

Therefore, in order to create a better VR experience, this article uses the HMD device HTC vive to produce the immersive VR courseware. Guoxiang Zhang, teacher in the Cross-border Software Company in Suzhou which is committed to VR education, said that VR educational effect is able to be better if learning time is controlled under 15 minutes a day, and 7 minutes each time. For primary and junior high school students, the deterioration of eyesight caused by VR experience is not allowed. Therefore, it should be noted that VR courseware can only serve as an auxiliary role in the classroom. It can't replace a teacher's position.

3.1 Teaching Objectives of the Courseware

Following the standard of junior high school biology teaching book, we set the teaching target:

1. To make users know the structure of the eyeball, the visual principle of the eye, the cause of myopia and hyperopia

2. To stimulate learning motivation in biology

3. To achieve the sublimation of knowledge through self-exploration in a virtual environment

In VR class, teacher explains the knowledge and encourages students to carry out discussion after the simple exploration of the structure of eyes. Students take the Helix ascending learning through the courseware.

Based on this, this study suggests that the VR eyeball courseware can be set to four parts, including the structure of the eyeball, the principle of how eyeballs build images, the causes and correction methods of myopia and the expanded knowledge about hyperopia.

3.2 Interactive Design & Technical Detail

The interaction mainly contains the model design, scene design and human-computer interaction design.

Eyeball is the main resource for this system. To model it, we make a detailed design for each part of it. At the same time, we have modeled the experiment classroom and provided learners with the best experience in a highly simulated environment. (Fig2) And there are two main scenes: scene one is the laboratory corresponding to the actual scenario and scene two is the virtual scene corresponding to the virtual environment. Learners have different interactive perspective in different situations.

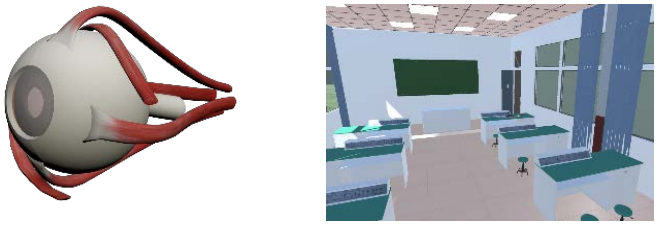

Fig. 2. Models of this courseware

As for the developing environment, we chose Unity3D which is the most popular game engine on the market. And two plugins were used: Steam VR and VR_TK. The design process of the system is as follows.

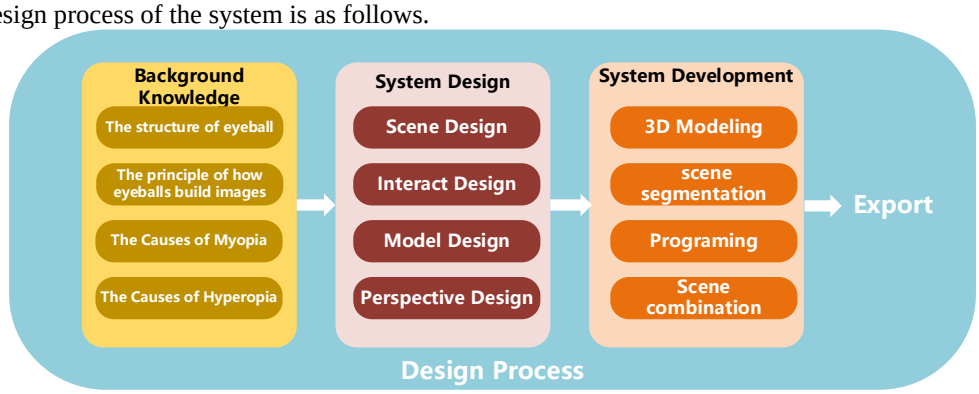

Fig. 3. Design Process

3.3 Content Design

3.4.1 The structure of eyeball

1. Scene one. On the blackboard writes a chalk textured text "structure of human eyeball" right in front of the eye model. Users can rotate, scale and move the model freely to see its detailed structure.

2. Switch to “scene two”. The detailed structure of eyeball is presented with descriptive texts floating next to corresponding parts. Users can interact with each part. (Fig.4)

In this section, the structure of the eyeball is introduced to enhance the student's impression of the eyeball and stimulate their learning motivation through self-exploration.

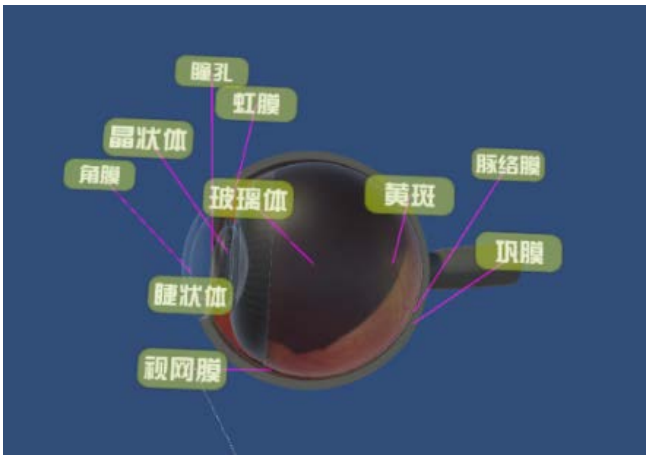

Fig. 4. The structure of eyeball in “scene two”

3.4.2 The principle of how eyeballs build images

Learners will be given a question of how human eyes can detect light through audio. With this question in mind, the elementary theory of how eyeballs build images will be illustrated through an example of how human will build an image of apple in brains.

In this part, with curiosity and doubt, users learn the principle of eyeballs to see objects and achieve a fusion of knowledge by an embodied cognition.

3.4.3 The Causes and Correction Methods of Myopia

1. Switch back to the “scene one” and play the record with the corresponding animation “myopia is one of the eye diseases modern adolescents suffer. When normal people see objects far away, the ciliary body relaxes and the lens becomes thinner, then the light passes through the lens and converges on the retina. Nonetheless, myopia is not like this”.

2. One of the reasons for myopia - The lens is too thick.

By pressing the vive joystick touchpad button to trigger the light, the image will be converged in front of the retina through thicker lens. Convergence point is highlighted and blinks twice. The corresponding explanations will be playing: There are two kinds

of myopia: one is refractive myopia. The lens is too thick so that its refractive power becomes stronger, thus the light coming from a distant point will converge in front of the retina before reaching. It's not a point but a blurred bright spot when arriving at the final. After broadcasting all the animation, the "jump button" will appear which used to tell users another reason for myopia.

3. Another reason for myopia- Ocular axis is too long

When the eyeball is too long in the anterior-posterior direction, light from a distance point will gather in front of the retina. The result is the same as the refractive myopia - when it arrives at the retina, it is not a point but a blurry bright spot. Similarly, the light triggered by Vive joystick touchpad-button passes through a long ocular axis, finally converges in front of the retina.

4. Embodied experience: From the perspective of the myopic eye in the virtual world, the scenery outside the window is blurred and the words on the book can only be seen in very close distance. (Fig.5 is the embodied experience)

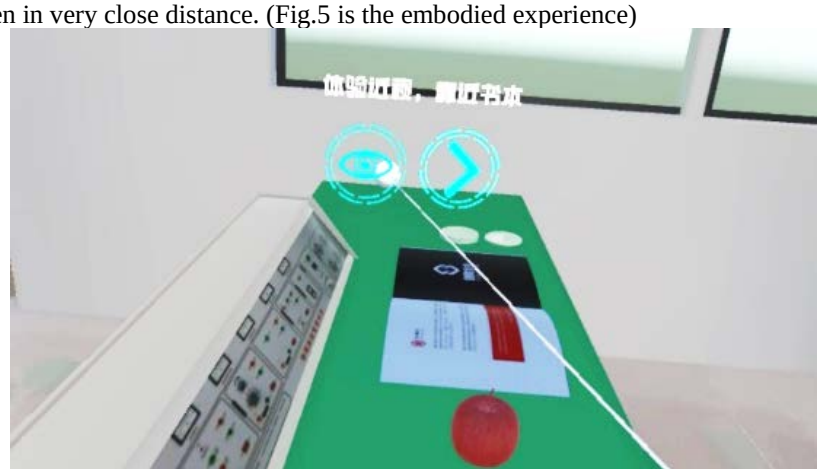

Fig. 5. Experience Myopia in "Scene one"

5. Myopia correction: In the virtual scene, put glasses on a myopic eye. The light will diverge through the concave lens and then converge on the retina through the lens and other parts. The convergence point will highlight and flash twice. Then the scene will be clear.

In normal classes, students already have a preliminary understanding of the textbook knowledge. Through this part of the experience, learners have a profound impression on the principle of eye myopia. And they can discuss the causes and correction of hyperopia. Finally, expanded knowledge will be introduced in the last part.

3.4.4 The Causes and Correction Methods of Hyperopia

Switch back to the "scene one" and play the record with the corresponding animation: Hyperopia is one of the eye diseases suffering modern adolescents. When normal people see objects far away, the ciliary body shrinks and the lens becomes thicker, then the light passes through the lens and converges on the retina.

The reason for hyperopia is Contrary to myopia, this section presents the two reasons for hyperopia (the lens is too thin / the ocular axis is too short) in the same method.

This part is to expand the student's horizon. The knowledge is also being improved and consolidated through Embodied experience.

4 Conclusion

The research reviews the virtual experiment based on various immersive HMD and its applications in teaching, designs and develops a set of HTC vive (PC VR headset) teaching courseware- Miraculous eyeball with the knowledge of high school biology. When designing the courseware, we considered and integrated instructional theory such as cooperative learning, embodied learning, inquiry learning and spiral ascension learning. The research aims to provide a VR experimental courseware model through the design and production of this product.

Through this study, we believe that the design and development of VR courseware resources not only need premium equipment and technology but also require to combine the correct teaching strategies and theories. A right teaching theory is the basis for guiding the classroom, is the strong support for teachers in class, is the fountain of student's motivation. The teaching will be colourful if the application of VR is controlled rightly in teaching time and manner.

At the same time, this study also has its own shortcomings. First of all, the content of system design is too much, which may cause cognitive load on some people. Secondly, we haven't conduct a wide range of teaching practice to prove the effect of courseware. Therefore, our future plan is to optimize the courseware on the basis of class teaching research.

The virtual reality technology is at the intersection of positively changing in 2018. As the multi-modal interaction technology becomes mature and AI become fiery. VR also seeks its own orientation in education. Although the new teaching model brought by VR technology is still only a prototype at present, and there is still a large space for us to imagine and improve. I firmly believe that, with the improvement of technology and the reduction of cost, VR will gradually become mature and will have more diversified applications in education and teaching in the future.

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Reference

1. Zhao, Q, P.: Review of Virtual Reality. Science in China (Series F: Information Sciences). 39(01),2-46(2009).
2. Sutherland, Ivan E.: "The ultimate display." Multimedia: From Wagner to virtual reality (1965).
3. Didehbani, Nyaz, et al. "Virtual reality social cognition training for children with high functioning autism." Computers in Human Behavior. 62: 703-711(2016).
4. Huang, R, H., Zheng, L, Q., Cheng, W.: The Learners Cognition and Credibility of Virtual Experiments. Open Education Research. 18(06), 9-15(2012).
5. Ding, N.: Wang, Y, M.: The Application of Virtual Reality in Education: Advantages and Challenges. Modern Educational Technology. 27(2), 19-25(2017).
6. Li, J.: Application of Virtual Reality Technology in High School Biology Teaching. Primary and Secondary Information Technology Education (1), 64-66(2018).
7. Jonassen, David H., et al.: Learning to solve problems with technology. Pearson Education (2003).
8. Gao, Y, D., Yan, X, M., Li, X.: Design and Implementation of Immersive Virtual Reality Venue: Taking the Development of Red VR Memorial in Practical Teaching of Ideological and Political Courses as An Example. e-Education Research 38(12), 73-78+85(2017).
9. Shi, T, J.: The application of virtual reality in education. Northeast Normal University (2008).
10. Zhou, Y.: Cardboard Interaction Design and Development of Virtual Reality Application. Hubei University of Technology (2017)
11. Yang, X, P.: Application Research of Virtual Reality Technology Based on unity3D in Middle School Physics Teaching. Shanghai normal university (2015).
12. Cui, R.: The Research of Realization and Effect of Independent Inquiry Learning Based on VR Technology--Take the Replication of DNA from Biology Course of High School for Example. Jiangxi science and technology normal university (2015).
13. Wang, C, X., Li, H., Shang, J, J.: Application and Development Prospect of Educational Games Based on Virtual Reality and Augmented Reality. China Educational Technology (8),99-107, (2017).
14. Gu, H., Sun, Z, J., Li, Q.: Research of Actual and Virtual Combined Experimental Teaching Model in Biology. Research and Exploration in Laboratory 35(4), 108-110, (2016).
15. Xu, J., Sun, R., Deng, X, F.: Application of virtual reality (VR) technology in high school biology class. Biology Teaching 42(03), 46-47, (2017).
16. Chen, J, J.: Design and Application of Virtual Simulation Experiment Based on VR Narrative, Central China Normal University (2017).
17. Song, H, M.: The Research Design of Handheld Individual Solider Psychological Adjustment Instrument. Summary of the 19th national conference on psychological science (2016).