Design and Practice of Exploratory Virtual Experiment in Physics Discipline

Yu Shufan
School of Educational Information Technology
Centeral China Normal University
Wuhan,China
yushufan1993@gmail.com

Liu Qingtang
School of Educational Information Technology
Centeral China Normal University
Wuhan,China
liuqtang@mail.ccnu.edu.cn

Xu Suxiao
School of Educational Information Technology
Centeral China Normal University
Wuhan,China
381126663@qq.com

Yang Yuanyuan
School of Educational Information Technology
Centeral China Normal University
Wuhan,China
1054129339 @qq.com

Wu Linjing
School of Educational Information Technology
Centeral China Normal University
Wuhan,China
wlj_sz@126.com

***Abstract*—Exploratory experiments are fundamental to physics courses. Virtualization technologies like XR can enhance students' learning effectiveness with a suitable experimental instructional design. At present, the research on the theory and strategy of designing virtual experiment is relatively rare, especially in physics discipline. This paper concludes the design principles of exploratory virtual experiment. Physics experiment in the K-12 textbooks titled "polarization of light" has been chosen for its mapping into virtual domain. Finally, a preliminary assessment and result will be presented.**

Keywords—Physics virtual experiment, XR technology, Design principle

I. INTRODUCTION

Experiment is an important method of human cognizing and transforming the world, especially in engineer and science fields. In physics classes, experiment-based exploratory learning is important for students to understand the basic knowledge and principles. China has listed scientific inquiry as the first part of the high school physics curriculum standard [1]where raising questions, conjecture and hypothesis, designing experiments and making plans, conducting experiments and collecting data, analysis and argument, assessment, communication and cooperation are the basic elements.

As educational informatization and multimedia technology become more and more mature, the application of XR technology in education is gaining its popularity. In this situation, the virtual experiment was "born". As early as 1989, Willian Wolf of UVA(University of Virginia) [2] proposed that virtual laboratory is a virtual environment based on computer networks. Then the concept of virtual experiment was introduced. In general, it means simulation and emulation of traditional experiments with the help of multimedia, computer networks and XR technology. Compared to traditional experiments, virtual experiments have the following advantages: 1. It can present the spatial relationship and the internal structure of the object perfectly 2. It can simulate a specific scene and perform experiments that can be dangerous if performed wrong 3. It can save a considerable amount of costs by appropriate methods when it comes to expensive instruments [3].

Although virtual experiment is popular in education, many researchers only focus on the technology itself [4]. Technology-oriented thinking faces some problem: 1. Monotonous UI design. The 3D-instrument models are not vivid and 2D-interface is too complex to express it clearly. 2. Insipid experiment process. Small amount of information and One-way transfer of knowledge (from teacher to students) make students be puzzled about knowledge. 3. Lack of feedback. Learners may not have a right self-awareness without helpful feedbacks. So a good educational design is necessary when we are building a virtual experiment courseware.

Debate about how to create a better virtual experiment still continues. In this paper, the principle on developing physics virtual experiment will be presented by reviewing several cases from the literature. Taking "polarization of light" in Chinese middle school textbook as an example, we then developed an exploratory physics virtual experiment.

The rest of this paper will be organized in the following order: the second part summarizes the design principles of physics virtual experiment. The third part introduces the design process of our practice-"Polarization of Light ". The last part is the summary and outlook of this work.

II. DESIGN PRINCIPLES OF EXPLORATORY PHYSICS VIRTUAL EXPERIMENT

A. Middle school physics experiment

Middle school physics is a subject related to natural science based on experiment, " Curriculum Standards of Physics for Ordinary Senior Middle School" puts forward 7 basic elements as we present in the first part of this paper. It is observed that experiments occupy a large amount of time in middle school physics classroom.

978-1-5386-6522-0/18/$31.00 ©2018 IEEE 4-7 December 2018, Wollongong, NSW, Australia
2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)

For further understanding, we classify physics experiments from the textbooks of the People's Education Edition into 6 categories.

TABLE I. PHYSICS EXPERIMENT IN PEP TEXTBOOK

Type	Amount	Representative case
Electrical experiment	52	Circuit connection…
Acoustic experiment	11	Sound propagation condition…
Optical experiment	35	Double slit interference experiment…
Electromagnetic experiment	38	Magnetic effect of current…
Thermal experiment	13	Molecular diffusion…
Mechanical experiment	98	Simple pendulum and double pendulum…

As the table1 shows, nearly 250 experiments are in the physics curriculum. Thus an excellent experiment is indispensable when students learn and apply physics experiment skills and scientific inquiry methods.

B. *Design principles for exploratory virtual experiment*

In experiment curriculum, inquiry learning will happen at any time. For an exploratory experiment, American educator Joseph J. Schwab [5]proposed three different methods for teachers:

- Students carry out experiments according to Lab manual or textbook to find unknown relationship between knowledges.
- Textbook only asks questions, and the research plan and the answers to the questions are left to the learners to propose.
- Learners ask questions directly, collect evidence, and present scientific explanations based on their own research without asking questions in the textbook.

This laid the foundation for the research of experimental theory. More researchers put forward their idea about exploratory experiment.

Wang et al. consider that virtual resources should be guided by the right pedagogy [6]. Followed by the three design philosophy "Co-study & Co-construction, virtual-real integration, extended sharing", it can be designed in four steps: 1. Identify resource types. 2. Refine design scripts. 3. Write design specification. 4. Design and implementation. Xing Hongjun proposed five design theories of physics experiment [7] based on Piaget's equilibrium model, including "Inquiry-based, funny, simple, combination theory with reality, scientific" principle. And 7 years later, Zhou Meirong of Jiangxi normal university added progressive, effective, creative, feasible and security design principle [8] to extended Xing's theory to 10 aspects. Shan et al. proposed the principle and application method of virtual experiment [9]. Zhu's research is about instructional design on virtual experiment [10].

The majority of these studies are on the theoretical level and reality level. When it comes to practice and virtual environment, we should pay attention to something else. According to the design thought above, combining our specific experience, this paper formulates a further design principle on virtual exploratory physics experiment.

1) *"Applicable Experiment" Principle*

As it is shown above, the amount of physics experiment is large and the variety is quite rich. Therefore, it is critical to decide with experiments which are suitable for virtualization. [11].

a) *Not every part needs to be virtualized*

Not all experiments are suitable for virtual version, virtual experiments cannot completely replace real experiments [12]. Some basic experiments only use some simple experimental instruments which are easy to operate. Under the existing conditions, the experimental tasks can be completed well with real experiments and achieved expected effect. The "real" is enough in this situation, such as how use a voltmeter, measure a simple object and so on.

b) *"virtual" and "real" complement each other*

The type of experiment is not always unchangeable, so we should choose the right time to "real", the right time to "virtual" and the right time to combine them based on the practical situation and student's cognitive level. For example, Mannus F et al. use the real magnets to feel the repelling and attraction and use AR technology to simulate the virtual magnetic field [13].

2) *"Rational Design" Principle*

A good design is important for a system. This is also applicative in the field of virtual experiments. At the same time, we should take the rational design principle into account. The UI, Models and Images, even the background music should be designed according to the specific case and the equipment performance. For instance, In biological field, Luden.io [14] continuous release several educational VR games such as InCell. with a bit of strategy and science thrown into the mix, learners can take an exciting journey inside the highly unusual micro world of human cell and stop the virus advance. The first-person design and the Sophisticated model highlight this gamification case features. As we can see in Figure1.

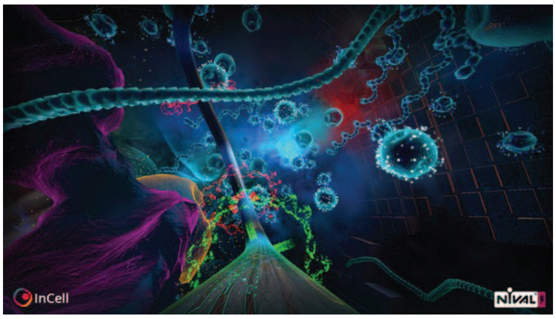

Fig.1 specific case- InCell

3) *"Suitable Method" Principle*

The growth of computing and immersive technology has provided various choices for designers. A suitable method to virtualize experiment plays a fundamental role in design process.

The most common technologies that can present virtual environment cover XR technology (Including AR, VR and MR), Flash technology and Web technology. There are already some researches indicate that XR technology is better in virtual experiment design [15]. So, this part mainly focused on XR technology.

a) Virtual Reality Technology

Virtual reality is a digital environment integrated with vision, hearing and touching generated by computer technology [16], it provides a fully virtual environment. Yu el al. has previously conducted a comparison among different categories of VR to find their application in classroom [17]. The most common and portable device is all-in-one headset. For physics experiment, the demonstration experiment is more suitable for it because of its immersive and portable characteristics. Such as Observe the crystal and non-crystal melting experiment. In China, Pico and IdeaLens (two all-in-one headset companies) has produced a lot of high-quality educational courseware by cooperating with some schools and agencies

b) Augment Reality Technology

Different from virtual reality, augmented reality is more emphasized superimposing computer-generated objects on realistic scenes. Its eye-catching advantages can unleash its potential in education [18]. Some eye-catching advantages, such as natural interaction, abstract content visualization and so on, have made AR become a potential technology in educational field. For instance, Wang et al. developed an AR-based interactive application on mobile devices to simulate the physical experiment “double-slit interferometer”, test shows it have positive effect on students [19].

c) Mixed Reality Technology

Mixed reality (MR) is a kind of computer virtual reality technology that makes real world and virtual objects display and interact in the same visual space [20]. Though a lot of giant effort has been put into it, this is still not a mature technology. Similar to AR, it can have a wide range application in physics experiment. For example, we can visualize the Flow of molecules in the reality.

4) “Outstanding Features” Principle

Mayer's cognitive load theory [21] in multimedia learning suggests that virtual experiments need to have distinctive characteristics. An “Outstanding feature” can reduce student’s cognitive load. For exploratory physics experiment:

a) Some cases need an accurate data presentation, such as“ Measurement Acceleration”, “Calculate the Resistance” and so on.

b) Some cases need an free exploration, such as “Circuit Assembly” , “Research on object flat throwing motion” and so on.

c) Some cases need a complete process to experience the steps of finding, forming, applying and improving knowledge, such as “Single Slit Diffraction” Experiment.

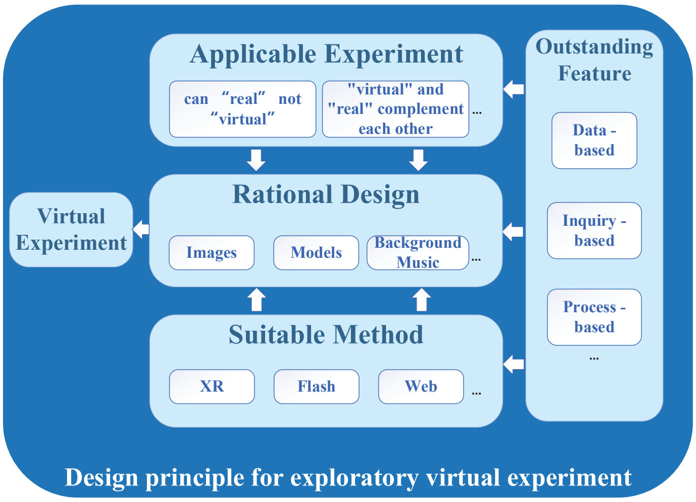

Fig. 2 Design principle

In general, the majority processes of the virtual experiment design include in these four principles. As the figure 2 shows.

III. Practice of Exploratory Physics Virtual Experiment -Polarization of Light

Polarization of Light is derived from the 6th section of chapter 13 in PEP Junior High School Physics Textbook. This section gives a brief introduction to the Polarization phenomenon and its application in our life with some images and a simple experiment guidance. Experiment provides a good method to express this part’s knowledge. By searching online, we found some experiment video tutorials and flash-based virtual experiment. For reality experiment, Polarization table is cumbersome and just suitable for a teacher-leading class, so students cannot have the firsthand experience to the experiment. For flash version, the instruments are only presenting in two-dimensional animation, students cannot acquire the immersive experience or freely explore the related knowledge. So it is feasible for us to design a XR-based experiment.

Based on the design principle framework, our work will be divided into four parts: Experiment, Method, Design, Feature, and a preliminary assessment will be presented at last.

A. Experiment

Polarization of light serves as a connecting link between the preceding and the following content to help students to know the Fluctuation of light [22].

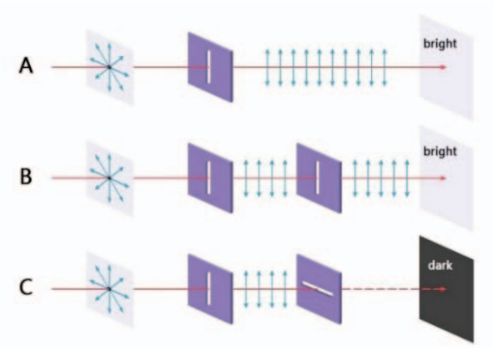

Fig.3 Polarization of light experiment

The experiment is divided into three parts, as figure 3 shows.

- When there is only one polarizer, the light intensity becomes a little bit weak. The polarizing plate can be rotated around the axis which accords to the direction of light propagation, and the intensity of light does not change.
- When the vibration directions of the two polarizers are parallel, the intensity of the light is the strongest, but it is weaker than light passing through one polarizer.
- When the vibration directions of the two polarizers are perpendicular, the intensity of the light is the weakest.

B. *Method*

For a free operation and 360-degree presentation, we choose AR as the simulation method for this case, and the Unity 3d engine as the develop tool, Vuforia as the AR platform, 3DS MAX & Photoshop as the design tool.

In order to have a better presentation, Image Target of Vuforia was chosen to carry out the experiment. Picture below is the target of this system.

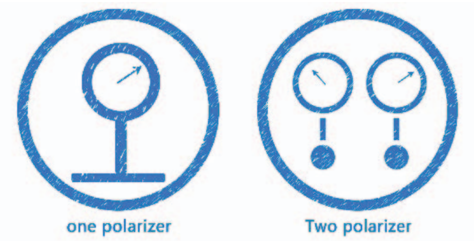

Fig.4 Image Target of this case

C. *Design*

1) *Model and UI*

Polarizer is the main instrument for this experiment system. To model it, we make a detailed design for each part of it, including pointer, dials and others. In order to present a better diffuse reflection, The optical screen is attached with a rough flat material.

For UI design, the control bar which can rotate the pointer was designed as a red ring. And we divided the system into two parts: exploratory mode, introduction mode. Figure 5 present the Polarizer Model and Menu UI.

Fig.5 Polarizer Model and Menu UI

2) *Content design*

As Wang [19] said, virtual experiment cannot completely replace real experiment. Thus, we design it as a way of assisting classroom teaching, and the system supports exploratory mode and introduction mode.

For exploratory mode (As shown in figure 5), the three parts of the experiment can be carried out. "One polarizer" and "Two polarizer" target respectively represent the situation A and the situation B, C in figure 3.

For introduction mode, the basic knowledge of "polarization of light" will be present. Student can consolidate knowledge about this after their personal exploration.

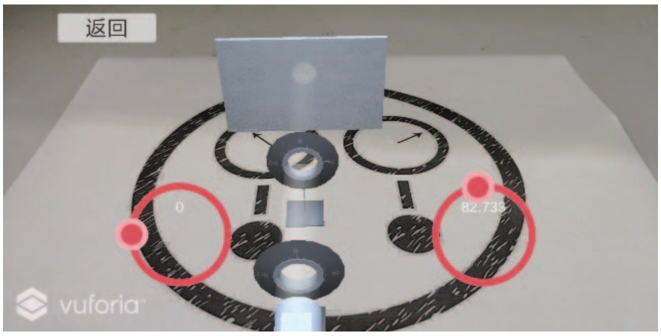

Fig.6 exploratory mode

D. *Features*

Data accuracy is the core feature of this system. Written in the textbook is that the brightness changes as the angle varies, and there is no way to know the specific values of light. According to the math algorithm, we develop it as follow:

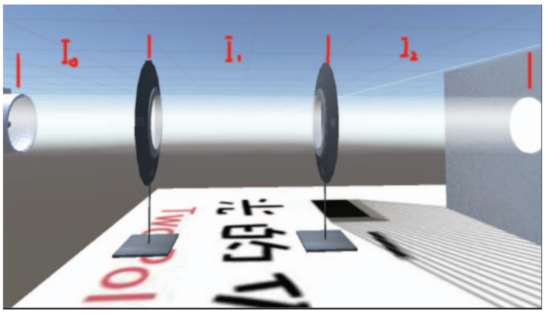

Fig.7 The experiment parameters

Assuming the intensity of original light is $\boldsymbol{I_0}$, light intensity through the first polarizer is $\boldsymbol{I_1}$, light intensity through the second polarizer is $\boldsymbol{I_2}$, light intensity of facula on optical screen is $\boldsymbol{I_3}$ and the angle between two polarizers is θ , we designed the experiment. As is shown in figure 7.

1) when it comes to the A situation in figure 3. Equation (1) shows the Light Intensity results.

$$I_3 = I_1 = \frac{1}{2} I_0 \qquad (1)$$

2) when it comes to the B,C situation in figure 3. Equation (2),(3) shows the Light Intensity results.

$$I_1 = \frac{1}{2} I_0 \qquad (2)$$

$$I_3 = I_2 = I_1 \cos^2 \theta \quad (3)$$

With the scientific calculation, this experiment shows ideal results.

E. Assessment

Three college students who have a certain understanding of the "polarization of light" knowledge but never experienced AR-based virtual experiment participated in our test. Firstly, a briefly introduction of this system was conducted. Then they freely explored the system to be familiar with the knowledge. A short interview was carried out at last.

The result of this interview shows:

- The instrument is vivid and the changes of light intensity conform to the reality
- This experiment utilizes one target to present the whole Polarization table, if one target represent one experiment instrument, the experience may be more interesting
- In general, students show a satisfied attitude towards this case.

IV. Conclusion

In this paper, principles on developing physics virtual experiment are presented by reviewing several cases from literatures. As an attempt, the experiment “polarization of light” was chosen to be virtualized by AR technology. For the portable characteristics of AR and mobile device, this virtual experiment can be performed at any time and in any place. Data accuracy also make this system deserve to explore.

At the same time, this study also has its shortcomings. First of all, the design principle which has only been proved effective in this experiment needs to be implemented into more experiments and further assess its robustness. Secondly, a wide range of teaching practice have not been conducted to prove the effect of this system, a further assessment is also our future plan. Thus, promoting this AR app to middle school teachers and students is our next step. One of our assumption is to utilize F. D. Davis’s Technology Acceptance Model (TAM) [23] to measure this system’s Perceived usefulness(PU) and perceived ease of use (PEOU), some of the app’s function will be tested and the learner’s attitudes will be presented.

It is believed that under the guidance of the advanced XR technology and the right design principle, exploratory virtual experiments will achieve greater development.

Acknowledge

This work is financially supported by self-determined research funds of CCNU from the colleges’ basic research and operation of MOE (NO. CCNU18JCXK03) and Chinese National Natural Science Foundation Project "Research on Machine Understanding Method for Math Word Problems" (No.61772012).

Reference

[1] W. J. Bai, “Research on teaching practice and application of the explorative virtual experiment in high school physics,” M.S. thesis, Dept. Educ. Tehcnology, Northwest Normal Univ., Gansu, China, 2014.

[2] W. A. Wulf, “The national collaboratory - a white paper. In J. Lederberg and K. Uncaphar, editors, Towards a National Collaboratory: Report of an invitational workshop at the Rockefeller University, Washington, D.C,” 1989.

[3] N. Ding, Y. M. Wang, “The Application of Virtual Reality in Education: Ad-vantages and Challenges,” Modern Educational Technology, vol.27, no. 2, pp. 19-25, 2017.

[4] X. Yang, H. L. Huang, X. F. Li, “Feedback design and implementation of virtual experiment,” China Educational Technology, no.7, pp.136-140, 2011.

[5] J. J. Schwab, “The teaching of science as inquiry,” Bulletin of the Atomic Scientists, vol. 14, no. 9, pp. 374-379, 1958.

[6] J. Wang, Y. Chen, “The New Fonm of Resources Construction:The Connotation and Design Framwork of Virtual Simulation Resources,” China Educational Technology, no. 10, pp. 991-96, 2016.

[7] H. J. Xing, “Design theory of high school physics exploratory experiment,” Curriculum,Teaching Material and Method, no. 9, pp. 32-35, 1999.

[8] M. R. Zhou, “Research on the Theory and Practice of Inquiry-based Experiments Design in High School,” M.S. thesis, Dept. physics Educ., Jiangxi Normal Univ., Nanchang, China, 2006.

[9] M. X. Shan, Y. Li, “Virtual experiment principle and teaching application.” Beijing: Educational Science Press, 2005.

[10] M. Zhu, “Virtual Experiment and its Application Studies in Teaching—Teaching of College Physics Experiment as an example,” ph.D. dissertation, Dept. Educ. Tehcnology, East China Normal University, (2006).

[11] F. Tian, “Integration of virtual experiment and real experiment,” Experimental Technology and Management, no.11, pp. 92-95, 2005.

[12] J. J. Wang, X. F. Wei, “The "hot" status and "cold" thinking of virtual experiment,” China Educational Technology, no. 04, pp. 126-129, 2011.

[13] F. Mannuß, J. Rubel, C. Wagner, F. Bingel and A. Hinkenjann, “Augmenting magnetic field lines for school experiments,” 2011 10th IEEE International Symposium on Mixed and Augmented Reality, Basel, 2011, pp. 263-264.

[14] Luden company.(2018). Introduction of incell product. Available: https://luden.io.

[15] M. B. Ibáñez, Á. Di Serio, D. Villarán, C. D. Kloos, “Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness,” Computers & Education, vol. 71, pp. 1-13, 2014.

[16] Q. P. Zhao, “Review of Virtual Reality,” Science in China (Series F: Infor-mation Sciences), vol. 39, no. 01, pp. 2-46, 2009.

[17] Q.T. Liu, S. F. Yu, L. Y. Lin, et al, “Design and Implementation of an Immersive Virtual Reality Biological Courseware—Miraculous Eyeball,” 2018 11th International Conference on Blended Learning. Springer, Cham, pp. 162-174, 2018.

[18] S. Cai, P. W. Wang, Y. Yang, et al, “Review on Augmented Reality in Education,” Journal of Distance Education, vol. 34, no. 05, pp. 27-40, 2016.

[19] T. Wang, H. Zhang, X. Xue, et al, “Augmented Reality-Based Interactive Simulation Application in Double-Slit Experiment,” REV2017-14th International Conference on Remote Engineering and Virtual Instrumentation, Columbia University, New York, USA, 2018.

[20] J. Huang, D. Q. Han, Y. Chen, F. Tian, et al, “A Survey on Human-Computer Interaction in Mixed Reality,” Journal of Computer-Aided Design & Computer Graphics, vol.28, no.06, pp.869-880, 2016.

[21] R. E. Mayer, “Multimedia Learning,” Cambridge University Press, 2001.

[22] W. S. Zhang, et al, “High school physics elective 3-4,” People's Education Press, 2007.

[23] F. D. Davis, “Perceived usefulness, perceived ease of use, and user acceptance of information technology,” Mis Quarterly, vol. 13, no.3, pp. 319-340, 1989.