Physical Visualization from the Perspective of Spatial Computing: Research on the Design of a Visualization Education System Based on XR Technology

Siyi Ye

College of Computer and Network Security, Chengdu University of Technology, Chengdu, China
ye.siyi@student.zy.cdut.edu.cn

Abstract. The invisibility of microscopic particles and complex spatial thinking are the two issues that challenge electromagnetism education in high school. To address the difficulty, this study suggests a new system of physics visualization education using Extended Reality (XR). This design takes into consideration the theory of Embodied Cognition, the Prediction-Observation-Explanation (POE) teaching strategy, and the philosophy of STEAM education. The relationship between virtual image and physical environment is implemented by the connection between the virtual image and the physical environment according to the video pass-through functionality of Apple vision pro. The research, through the assistance of the physical engine algorithm of Unity and gesture tracking technology, develops a multi-purpose teaching system of physics visualization, combining 3D space drawing, simulation experiments and exploration of flow of macroscopic particles. Students are able to directly engage with digital images in the real world, and convert the traditionally passive learning of electromagnetic fields into an exploration. This system forms a reasonable relationship between abstract mathematical laws and the intuitive physical laws. The effect of immersive perspective and real-time simulation makes students more cognitively rich and spatial in thinking. This study, by using interactive exploration to develop interest and motivation, provides a completely new solution to education challenges, overcoming theoretical abstractness in electromagnetism education.

Keywords: Extended reality, Unity, Vision pro, Visualization, Electromagnetism

1. Introduction

There are many intricate concepts in the high school physics curriculum, especially in electromagnetism. Due to the involvement of abstract microscopic particle movements and complex model vector analysis, traditional two-dimensional media cannot provide sufficient intuitive spatial teaching. And parts such as the Lorentz force and the motion of charged particles in a magnetic field have always been difficult points in teaching. In recent years, technology has continuously evolved and developed, and the application of extended reality (XR) technology has had a positive impact on education, especially for the cultivation of spatial analysis thinking in physics electromagnetism [1]. With the launch of various XR products like Apple vision pro, the visual presentation and interactive logic of XR technology have been enhanced. Video Pass-through technology allows the wearer to simultaneously perceive real-time virtual image and the physical environment [2]. Through the connection to the real classroom, XR technology can create immersive studying environments for students to achieve active exploration [3]. Relevant studies have shown that XR technology improves the efficiency of physics classes by providing visual teaching, optimizing cognitive load, and enabling tactile learning, etc. [4]. While the existing XR technology physics teaching tools which mostly focus on experimental demonstrations lack a complete teaching loop from force analysis to logical verification. Consequently, it is difficult to effectively address the core pain points of spatial thinking cultivation. The paper discusses how XR technology can be used in the electromagnetism course. Design a system that fits the Prediction - Observation - Explanation (POE) teaching strategy and STEAM education philosophy that uses the embodied interactivity of XR technology to obtain immersive learning of physics. It consists of three functions, three-dimensional space drawing, experimental experiment simulation, and exploration of the macroscopic particle flows. It enables the students to do active thinking and analysis, logical experiments and exploration experiences rather than passively receive the knowledge. Learning effects are enhanced by the association between the process of analysis and real physical laws. This study aims to synthesize various educational ideas and implement the XR visual teaching design on the basis of the fundamental features of spatial computing. This study will discuss the role of XR technology in developing spatial thinking of the students, in order to address the pain points in teaching physics as it has been traditionally taught, by creating an interactive scenario that considers the accuracy of physics and interest of students.

2. Method

2.1. Source of concept

2.1.1. Educational philosophy

Prediction - Observation - Explanation (POE) teaching strategy was formally proposed by researchers whiter and gunstone in 1992 and is mainly applied in the field of science education. This teaching strategy takes learners as the center, guides students to participate in inquiry learning through three processes of prediction, observation and explanation, and focuses on cultivating active thinking ability and dialectical thinking [5]. In the teaching mode involving XR technology, POE Teaching strategy can also improve students' cognitive ability. By integrating the core process of prediction, observation and interpretation with the immersion and interactivity of XR technology, students can actively think and explore in the virtual and real environment, effectively making up for the shortcomings of traditional teaching [6].

With the development of embodied cognition theory in the field of education, the teaching method can not only impart knowledge, but also add body perception and operation actions to enhance students' sense of participation in the learning process. Research shows that embodied education can reduce cognitive load and significantly improve academic performance [7]. Embodied design in physics teaching can be realized through gesture control, virtual data input and immersive exploration, making abstract concepts easy to understand and remember [8].

Steam education concept covers the disciplines of science, technology, engineering, art and mathematics, and aims to cultivate students' thinking ability and innovation ability by integrating different subjects, so as to improve students' comprehensive quality. Applying steam education concept to physics courses can stimulate students' interest and innovation consciousness, and thus strengthen the learning effect [9]. Based on XR technology, the integration of visual art helps to improve visual perception and memory, and brings benefits to the classroom [10].

2.1.2. Technology application

Based on video perspective technology (passthrough), it not only provides the wearer with virtual image images, but also projects the real physical world images in real time. So teachers can also pay attention to students' situation in time during teaching to help with class management. Apple vision pro connects the real world and the virtual world through the external camera of the device, while ensuring comfort and reducing the impact of discomfort caused by visual vertigo [2]. As a hardware carrier, Apple vision pro provides technical support for the visualization education system related to XR technology.

Unity physics engine can build an accurate physical model and simulate the physical behavior in the real world in real time. It can be selected as the core technology of simulation experiments. Based on the rigid body dynamics simulation algorithm, unity PhysX can process the movement, force, rotation and other effects of objects according to the algorithm to realize simulation [11]. At the same time, it also supports the simulation of particle system, and can generate different types of particles. Unity VFX can realize the movement and interaction of a large number of particles, generate particles with different effects such as smoke, sparks, water spray, and enhance the interest and visual effect [11]. As a development environment, the algorithm of unity physics engine can ensure the accuracy of motion trajectory and meet the preciseness of teaching knowledge.

Gesture tracking has been widely used in many fields, and is the core interaction mode of head mounted devices. Its convenience and immersion can adapt to the application related to XR technology. Arkit supports the detection and tracking of gestures and movements in the real environment through the camera [12]. The interaction between gesture and virtual image is suitable for the design of education system, and provides a suitable interactive mode for teaching.

2.2. Design strategy

In order to realize the visual education system which is helpful for the teaching of high school physics electromagnetism, and combined with the related concepts of POE Teaching strategy, embodied cognitive theory and steam education concept, this study designed a multifunctional physical visualization teaching system which integrates three-dimensional space drawing, simulation experiment simulation and macro particle flow exploration, and the three stages are deeply bound to the teaching objectives. During the teaching process, the teacher wears the equipment and synchronizes the first perspective picture on the screen of multimedia equipment in the classroom for students to watch.

Firstly, based on the gesture drawing function of airdraw in Apple vision pro, the first stage of three-dimensional space drawing which is named 3D Image is used for force analysis of particles, focusing on three-dimensional form to cultivate students' spatial thinking ability. This stage corresponds to the "prediction" link of POE Teaching strategy. The Embodied Cognition theory is realized through gesture operation, and the force of particles in space is drawn by gesture operation.

Secondly, after inputting the data, the virtual laboratory in the second stage named simulation experiment obtains the particle trajectory and plays it through the algorithm of the unity PhysX physics engine. It strengthens the cognition through the visual effect of conjecture and truth. Watching the particle movement process and reflecting on the force analysis process correspond to the "observation" and "explanation" of POE Teaching strategy respectively.

Finally, the third stage named Macro Display generates particle flow through unity VFX, which conforms to the steam education concept, integrates art into science, and allows students to explore in an immersive environment to improve their learning motivation.

3. Prototype scheme

As shown in Figure 1, in the initial interface of the system, the user wears the device to enter different stages by gesture clicking, and exits by narrowing the gesture.

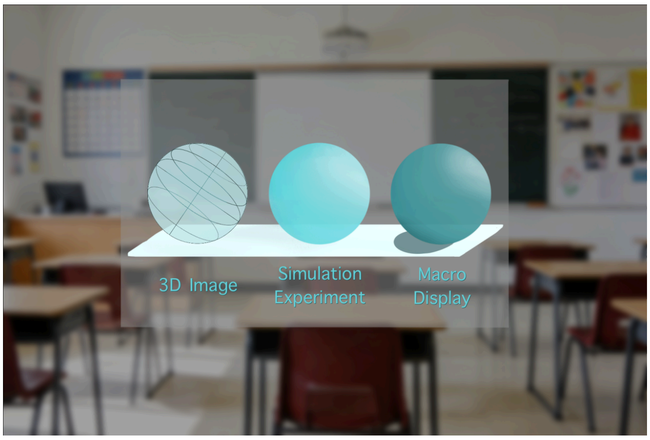

Figure 1. Initial interface (picture credit: original)

As shown in Figure 2, in 3D Image, the left palm controls the brush setting board, and the right hand modifies the settings and controls the direction of the brush. In the brush settings board, you can modify the brush color, thickness, and opacity, and support the functions of erase, return, and undo.

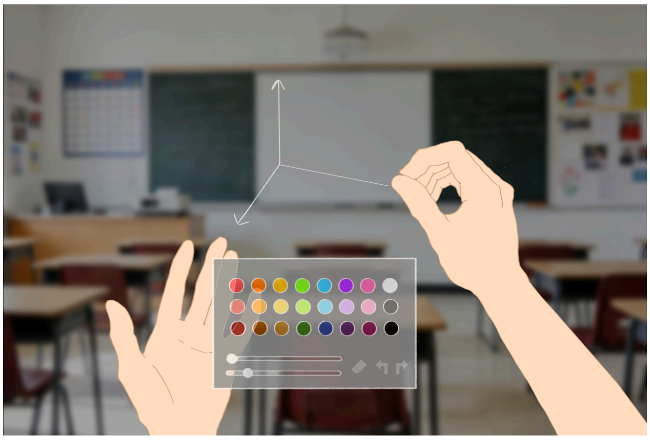

Figure 2. The interface of 3D image (picture credit: original)

After exiting the previous stage and entering Simulation Experiment, you can set the data and observe the simulation experiment in virtual laboratory. As shown in Figure 3, on the console below the line of sight, from left to right, there are "+" (add positively charged particles), "-" (add negatively charged particles), "m" (set magnetic field), "e" (set electric field), "clear", "pause" and "start" function marks. The use process of this stage is as follows: Firstly, click "M" or "E" and draw the magnetic field or electromagnetic range in the laboratory above. After the system generates the boundary, the magnetic field or electric field serial number will be displayed in the upper left corner, and the selection of different directions will be provided in the lower right corner. Click to confirm the direction and turn green. Secondly, drag "+" or "-" to the laboratory to generate corresponding particles at this position. After the system generates particles, the object list will be displayed in the upper right corner, and the selection of whether it is affected by gravity (G), magnetic field (M), and electric field (E) will be given. Click to confirm, and the affected objects will turn green. Thirdly, draw the velocity direction outward from the particle, and by default form a small angle deviation with the magnetic field or electric field (magnetic focusing spiral). Hold the hand for 2 seconds after painting, it will automatically correct the small angle deviation, which is parallel to the field (straight line) or perpendicular to the field (circle). The function of angle correction allows students to intuitively compare the difference between "non ideal angle (spiral motion)" and "ideal angle (linear or circular motion)". Finally, click "start" and "pause" to play and stop particle motion. Clicking "clear" button will empty the laboratory.

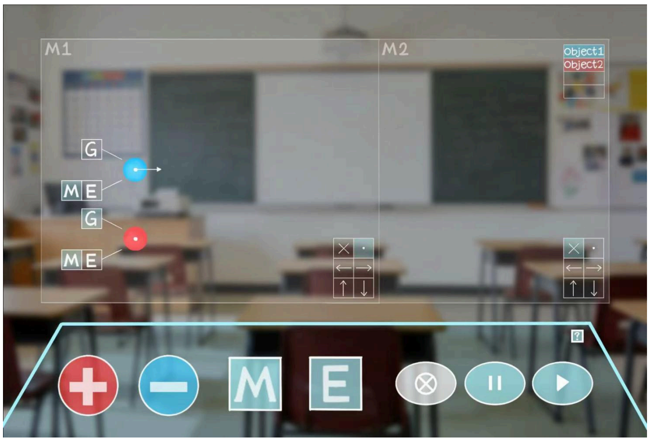

Figure 3. The interface of simulation experiment (picture credit: original)

The user can understand the meaning of the button by clicking the question mark button on the console. Then the details will be shown as Figure 4.

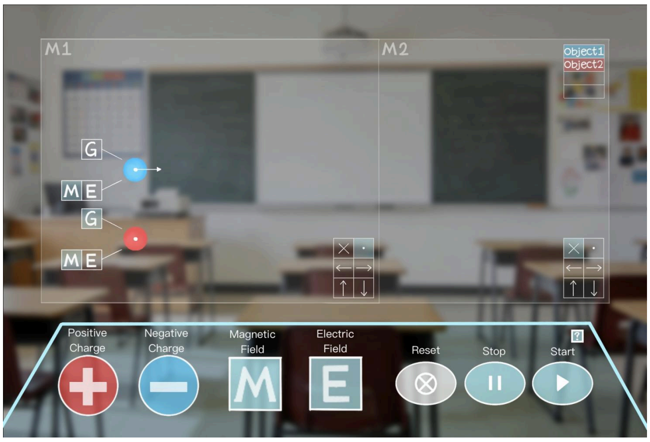

Figure 4. The interface of explanation of button (picture credit: original)

Enter the last stage of Macro Display which is used to explore the macro particle flow. As shown in Figure 5, the basic operation mode is to control the function board with the left palm and select and set with the right hand. The use process is as follows:

The first step is to draw the emission range of particles in the air. After the start, particles will appear at random positions in the range. The second step is to drag the particles to be generated into the emission range from the object list. Third, after dragging each particle, three turntables will appear in the system, namely number of emissions, emission time interval and number of each time. Slide the turntable by hand to adjust the data. Number of emissions controls the number of launches. The default value is 1, the minimum value is 1, and the maximum value is 20. Emission time interval controls the interval time of each launch, in seconds. The default value is 0.2, the minimum value is 0.05, and the maximum value is 2.0. Number of each time controls the number of particles emitted each time. The default value is 10, the minimum value is 10, and the maximum value is 500. Last, click "start" and "pause" to play and stop the particle flow demonstration. Clicking "clear" will clear the space.

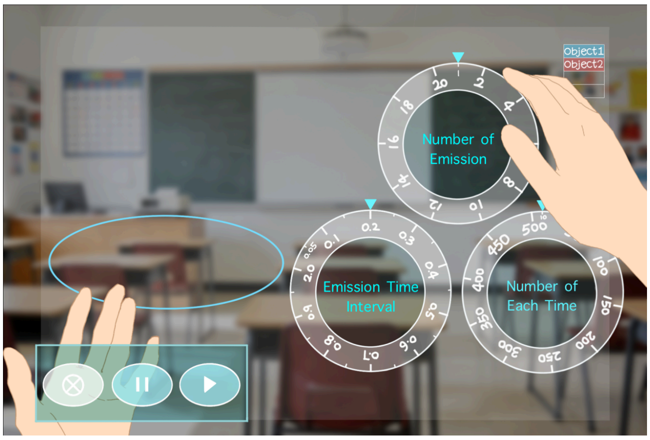

Figure 5. The interface of micro display. (picture credit: original)

4. Discussion

4.1. Challenge

This research needs to break through the following difficulties: First, balance the preciseness of physical knowledge and the interest of XR, so as to meet the laws of physics and stimulate learning interest at the same time. Second, pay attention to the convenience of operation, adapt to the cognitive level of high school students and meet the teaching needs. The third is to realize the deep landing and adaptation of multi education theory, and accurately combine the theoretical core with the system design.

4.2. Prospect

The existing prototype brings about a base system of physics learning with XR technology. Nevertheless, the system can be still enhanced in future. First of all, this project will be able to optimize the physical engine and improve the visual effect. Refine algorithm to give increased accuracy in modeling complex phenomena. Strengthen the visual effects technology, such as optimizing the macro particle flow to be more beautiful and artistic. Then, utilize gesture recognition technology to realize the interaction between wearer's hand and particle flow. The inclusion of haptic feedback enhances the embodied nature of the cognition. The project must also pay attention to enhance the comfort of the wearer to minimize the adverse influence on classroom teaching. Furthermore, the system has the potential to be extended to other modules of physics and other disciplines to form a multi-disciplinary XR teaching resource. Apply such a system to assist the students to overcome the challenges of spatial thinking on other knowledge points.

5. Conclusion

Aiming at the teaching pain point of high school physics electromagnetism knowledge, based on XR technology, combined with POE Teaching strategy, embodied cognitive theory and steam education concept, this study designed and developed a set of physics visualization teaching system which integrates 3D space drawing, simulation experiments, and macroscopic particle flow exploration. The system successfully transforms abstract electromagnetic concepts and laws into interactive and operable three-dimensional visual experience, which not only significantly improves the intuition and interest of knowledge presentation, but also effectively promotes the cultivation of students' spatial imagination ability and scientific inquiry ability. The difficulties of the research mainly lie in how to balance the preciseness of physical principles and the attraction of visual presentation, how to make the system design fit the actual teaching needs and adapt to different students' cognitive levels, and how to realize the deep integration and collaborative application of various educational theories in the technology platform. In the future, this project can further deepen from the aspects of technical function optimization, interdisciplinary content expansion and teaching support system construction, and gradually create a new ecology of immersive and interactive intelligent teaching with XR as the core.

References

[1] Malikova, Z., & Ualikhanova, B.(2025). TEACHING ELECTRICITY AND MAGNETISM IN HIGHER EDUCATION THROUGH VIRTUAL REALITY AND ARTIFICIAL INTELLIGENCE. In: 22nd International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2025). Portugal. 205-212.

[2] Vona, F., Schorlemmer, J., Stern, M., Ashrafi, N., Vergari, M., Kojić, T., & Voigt-Antons, J. (2025). Comparing Pass-Through Quality of Mixed Reality Devices: A User Experience Study During Real-World Tasks. 2025 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), 1432-1433.

[3] Ioannou, A., Bhagat, K. K., & Johnson-Glenberg, M. C. (2021). Guest Editorial: Learning Experience Design: Embodiment, Gesture, and Interactivity in XR. Educational Technology & Society, 24 (2): 73-76.

[4] Vdak, A., Movre Šapić, I., Mešić, V., & Gomzi, V. (2023). Augmented reality technology in teaching about physics: a systematic review of opportunities and challenges. European Journal of Physics, 45 (2): 1-43.

[5] Yang, XL. (2023). Discussion on POE Teaching Strategies Applied to Science Concept Transformation Teaching. International Journal of Education and Humanities, 9 (2): 92-94.

[6] Jiang, AC. & Li, GF. (2024). Enhancing cognitive abilities through the POE teaching strategy in a virtual learning environment. Cognitive Systems Research, 88: 1-12

[7] Lyu, CW. & Den, S. (2024). Effectiveness of embodied learning on learning performance: A meta-analysis based on the cognitive load theory perspective. Learning and Individual Differences, 116: 102564.

[8] Akdag, M. A., Botev, J. & Rothkugel, S. (2025). Enhancing Learning and Knowledge Retention of Abstract Physics Concepts with Virtual Reality. IEEE Transactions on Visualization and Computer Graphics, 31 (11): 9964-9973.

[9] Lu, S.-Y., Wu, C.-L. & Huang, Y.-M. (2022). Evaluation of Disabled STEAM -Students' Education Learning Outcomes and Creativity under the UN Sustainable Development Goal: Project-Based Learning Oriented STEAM Curriculum with Micro: bit. Sustainability, 14 (2): 679.

[10] Zhang, C. X. & Jia, B. C. (2024). Enriching STEAM education with visual art: education benefts, teaching examples, and trends. Discover Education, 3 (247).

[11] Lei, D., Liu, M. Y., Miao, L., Yang, T. T., Hu, Y. & Zhou, X. C. (2024). Numerical Calculation and Optimization Algorithm Based on Unity Physics Engine. 2024 IEEE 13th International Conference on Communication Systems and Network Technologies (CSNT), 1016-1021.

[12] Khan, S., Ali, S. A., Nadeem, M. & Chawla, R. (2020). AUGMENTED REALITY BASED GESTURE DETECTION & OBJECT CREATION SYSTEM USING XCODE & ARKIT. Edición Especial Special Issue Noviembre 2020, 79-91.