Article

Construction of Application Mode of Virtual Reality (VR) Technology in Hazardous Chemistry Experiment Teaching

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Abstract: Traditional hazardous chemistry experiment teaching has long faced problems such as high safety risks, insufficient experimental resources and limited teaching effects. In order to solve these dilemmas, this study deeply analyzes the application advantages of VR technology in this field, and combines constructivism theory, situational cognition theory and embodied cognition theory to construct a complete set of VR teaching mode, covering the whole process of experimental preview, classroom teaching and review assessment. By creating realistic virtual experiment scenes, designing interactive operation links and establishing dynamic feedback mechanism, this model guides students to change from passive knowledge acceptance to active inquiry learning. At the same time, the in-depth application of VR technology in hazardous chemistry experiment teaching has accelerated the transformation of chemistry experiment teaching to digitalization and intelligence, provided new ideas for the reform of experimental teaching under the background of educational informatization, and helped to achieve the dual goals of cultivating students' experimental operation skills and safety awareness.

Keywords: virtual reality technology; hazardous chemical experiments; application pattern construction

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1. Introduction

Chemistry experiment teaching is an important component of chemistry teaching. It can be said that the development of chemistry is based on experiments. From the perspective of the development of chemistry, chemical experiment is an important research method to explore the properties of matter [1]. However, dangerous chemical experiments involve many chemical reagents with flammable, explosive, highly toxic and corrosive characteristics, as well as extreme experimental conditions such as high temperature, high pressure and strong radiation, which not only threaten the lives and health of teachers and students, but also may cause environmental pollution. In order to avoid these risks, many schools have to reduce students' hands-on experimental operations in the teaching of dangerous chemistry experiments, and instead adopt alternative methods such as teachers' demonstration, playing experimental videos and explaining experimental principles. Although these methods can transmit experimental knowledge to a certain extent, students can't participate in the experimental operation personally; it is difficult to understand the details of the experiment deeply, and the cultivation of practical ability and innovative thinking is also greatly limited. Moreover, the traditional teaching mode also faces some problems such as shortage of experimental resources, aging of experimental equipment, insufficient experimental sites, and "confirmatory experiments", which further restrict the improvement of the teaching quality of hazardous chemistry experiments.

In November, 2019, the Opinions on Strengthening and Improving Experimental Teaching in Primary and Secondary Schools issued by the Ministry of Education pointed out that schools in various places should enrich the implementation forms of experimental teaching and comprehensively use observation, observation, simulation, experience, design, programming, production, processing, feeding, planting, visiting, investigation and other methods to promote the organic integration of traditional experimental teaching and modern emerging science and technology, effectively enhance the interest and attraction of experimental teaching, and improve the quality and effect of experimental teaching. Things and phenomena that cannot be observed and controlled in the real world due to time and space limitations, processes that change too fast or too slowly, and experiments that are dangerous, destructive and harmful to the environment can be presented by augmented reality, virtual reality and other technical means [2].

With the rapid development of science and technology, VR technology has brought new opportunities for the teaching of dangerous chemistry experiments with its unique immersion, interactivity and conception. VR technology can create a highly realistic virtual experimental environment through computer graphics, sensor technology, simulation technology, etc., allowing students to conduct dangerous chemical experiments in a safe virtual space and gain an immersive experimental experience. Integrating VR technology into hazardous chemistry experiment teaching is expected to break the bottleneck of traditional teaching, solve problems such as potential safety hazards and resource constraints, improve teaching effects and promote students' all-round development. Therefore, it is of great theoretical significance and practical value to deeply study the application mode of VR technology in hazardous chemistry experiment teaching.

2. Application Advantages of VR Technology in Hazardous Chemistry Experiment Teaching

With the development of virtual reality technology, VR has gradually entered people's lives and subject teaching [3]. Applying VR technology to chemistry experiment teaching can not only solve the above problems to a great extent, but also improve the efficiency of experiment teaching and stimulate students' interest in experiment exploration. The advantages of VR technology applied to chemistry experiment teaching are mainly manifested in three aspects: safety guarantee, holographic immersion, and flexible experimental condition control.

Flexible experimental condition control: Traditional chemical experiments need to be carried out in chemical laboratories or specific test sites, using chemical instruments and experimental drugs, and completing the learning of experimental operations according to the specified time. During the experiment, students may not be able to continue because some poorly done steps, and because the time of the course is tight, students can't complete the experimental operation at anytime and anywhere. Virtual reality technology frees operators from limitations of time and space. They only need to install the experimental software virtual simulation computer, and they can complete the experimental simulation anytime and anywhere, and skillfully experience the operation steps. To satisfy and improve students' learning needs to the maximum extent, the overall efficiency of experimental teaching is improved.

Holographic immersion: refers to the fact that users can get an immersive sense of reality in the virtual environment, as if they were part of the virtual world. Users can be completely surrounded in the virtual environment through VR devices, such as head-mounted displays, where senses like vision, hearing, and touch receive stimulation from the virtual world, leading to cognitive resonance and psychological immersion, making it difficult to distinguish virtual from reality.

Safety guarantee: Traditional hazardous chemical experiments involve toxic, flammable, explosive chemicals and dangerous operating environments such as high temperature and high pressure. Once the operation is wrong, it is easy to lead to serious safety

accidents such as poisoning, fire, and explosion. By constructing virtual experimental scenes, VR technology eliminates potential safety hazards such as chemical leakage, explosion and burn from the root cause without contact with real dangerous chemicals and experimental devices. At the same time, the VR system can monitor and limit students' wrong operations in real time. For example, when students mix wrong reagents or use irregular instruments in a virtual environment, the system will immediately issue a warning and prevent the continuation of dangerous behaviors, creating a zero-risk experimental learning environment for students, so that students can fully master the operation skills and knowledge points of dangerous chemical experiments on the premise of safety.

3. Theoretical Basis of VR Technology Applied to Middle School Chemistry Experiment Teaching

3.1. Constructivist Learning Theory

Constructivist learning theory emphasizes that the acquisition of knowledge does not depend solely on the one-way teaching of teachers. Learners need to flexibly use all kinds of learning resources in specific social and cultural situations, with the help of external support such as teacher guidance and peer collaboration, and realize a deep understanding and mastery of knowledge by actively constructing the meaning of knowledge. Among them, "situation creation", "collaborative learning", "interactive communication" and "meaning construction" constitute the core elements of learning environment, which profoundly affect the effectiveness of learning.

The VR chemistry experiment teaching scene should be constantly integrated with the original teaching mode, complement and enhance the existing teaching methods, promoting innovation and improvement. Students are exposed to a highly simulated virtual experimental environment, and can independently design experimental steps, operate experimental instruments, and observe chemical reaction phenomena in real time. Through this immersive exploration, students actively think and construct chemical principles and laws based on existing cognitive experience, transform abstract knowledge into concrete understanding, and realize the transformation of learning mode from passive acceptance to active inquiry.

3.2. Situational Cognitive Theory

This theory holds that the learning and application of knowledge cannot be separated from specific situations. "Situation" is also regarded as the coordinated relationship between man-machine-environment. The construction of the design situation can be a real environment or a virtual environment, which enables the experiencer to establish the connection between the cognitive structure and the knowledge learned in the cognitive process, so as to acquire knowledge more efficiently, promote experience and improve cognitive initiative. VR technology can highly restore the real situation of chemical experiments, including laboratory environment, instrument and equipment operation, chemical reaction process, etc. Students can better understand the application of chemical knowledge in practice and improve their ability to solve practical problems by learning in realistic situations.

3.3. Embodied Cognitive Theory

Embodied cognitive theory emphasizes that cognition is not an abstract process isolated from the body, but a dynamic result generated by individuals through body perception, action and interaction with the environment. In the operation scene of VR chemistry experiment, this theory has been fully confirmed and expanded: students wear somatosensory interactive devices such as VR equipment and control handles, and complete experimental operations such as drug taking, instrument assembly and condition adjustment with concrete body movements such as grasping, rotating and dumping, so that the original abstract experimental steps can be transformed into perceptible and repeatable

embodied practices. This interactive method based on body movement constructs a closed-loop learning cycle involving action execution, visual feedback, and cognitive processing. Compared with the observation and memory learning methods in traditional experimental teaching, VR experiment changes knowledge acquisition from passive reception to active construction. Through the direct participation of the body, students can realize the deep internalization of experimental principles, operational norms and safety guidelines under the synergy of muscle memory and cognitive understanding, so that the learning process can break through the surface memory and achieve embodied cognitive integration and skill transfer.

4. Construction of Application Mode of VR Technology in Hazardous Chemistry Experiment Teaching

4.1. Build a Virtual Experiment Platform

Develop a middle school chemistry experiment preview platform based on VR technology, and integrate experiment-related teaching resources, including videos explaining experimental principles, 3D experimental instrument models, virtual experimental operation demonstrations, etc. Students can enter the platform by wearing VR devices, and can choose their own experimental projects for preview. Teachers can monitor and manage students' experimental progress and record relevant data such as login information, operation steps, and operation time.

4.2. Application Pattern Construction

The path and method of deep integration of information technology and subject teaching involves three aspects: content, methods, and tools [4]. On the premise of accurately focusing on teaching objectives, teachers should make use of information technology to make efforts to break through and solve important and difficult problems. In classroom teaching, teachers use information technology to point to the core of problem solving, and cultivate students' deep thinking of analysis and evaluation in the process of building knowledge, which is the core and greatest value of information technology application [5]. The specific mode is shown in Figure 1.

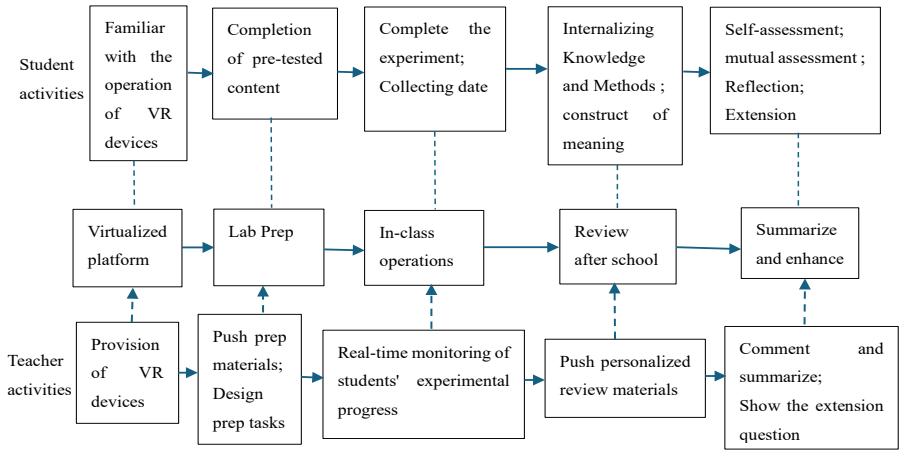

Figure 1. Application Mode of VR Technology in Teaching.

Pre-class preview: Teachers release VR experiment preview tasks through teaching management software, and students use VR equipment to enter the virtual experiment scene in advance to understand the purpose, principle, steps and precautions of the experiment. Graphic descriptions, animation demonstrations and voice explanations in virtual scenes help students quickly master the key points of the experiment and prepare for classroom experimental operations. After the preview, students complete the preview test

questions set by the platform, including multiple-choice questions, fill-in-the-blank questions and short-answer questions, to test their mastery of experimental knowledge. According to the test results, the system generates personalized learning reports, points out the weak points of students' knowledge, and provides reference for classroom learning.

Classroom experimental operation: Students wear VR equipment in class and enter the virtual laboratory for experimental operation. During the operation, the system records students' operation data in real time, and sends out timely prompts and correction information for wrong operations. For demonstration experiments that are not obvious, difficult to display in class or have security risks, VR technology is used to display them. By controlling the VR equipment, the teacher projects the experimental images onto a large screen and leads the students to observe the experimental process together. In addition, VR technology can also support online interactive communication. Students can have real-time discussions with other students in a virtual environment and share their learning experiences. This interactive learning method can cultivate students' teamwork ability and promote knowledge exchange and sharing.

After-class review and summary: Students can log in to the VR experimental system again after class, and can choose different review modes according to their own learning situation, such as "key review mode" to reinforce learning for their weak experimental knowledge points; The "comprehensive review mode" systematically reviews multiple related experiments. According to the students' experimental data and classroom performance, teachers summarize and evaluate, analyze the problems existing in students' experiments, put forward targeted improvement suggestions, and feed them back to students through teaching management software.

Feedback and evaluation: In order to ensure that the deep integration of VR technology can achieve good results in middle school chemical hazard experiment teaching, an effective feedback and evaluation mechanism must be established, including collecting students' feedback, evaluating students' learning effect, and adjusting the teaching mode. Through real-time monitoring and data analysis, teachers can fully understand students' learning status, adjust teaching strategies in time, and improve teaching quality and effectiveness.

5. Practical Significance of VR Technology in Hazardous Chemistry Experiment Teaching in Middle Schools

5.1. Ensure Experimental Safety in an All-Round Way and Eliminate Teaching Worries

In the traditional dangerous chemistry experiment teaching, the corrosiveness of concentrated acid and alkali, the instability of flammable and explosive reagents, and the potential threat of toxic gases are always the "sword of Damocles" hanging over teachers and students. Even with protective equipment and strict operating specifications, it is still difficult to completely avoid safety accidents caused by operational errors. By constructing a virtual experimental environment with full-scale realistic simulation, VR technology completely cuts off the source of safety risks without contact with real hazardous chemicals and instruments during operation. For example, in the chlorine preparation experiment, students can operate freely in the virtual environment without worrying about chlorine leakage poisoning; In the reaction experiment between metal sodium and water, even if wrong operations such as excessive investment are carried out, the system only simulates the explosion scene through visual effects, without causing any actual damage. This zero-risk experimental mode not only protects the safety of teachers and students, but also enables teachers to carry out teaching with confidence. Students can try to operate more boldly, completely eliminating the concern of students being overly cautious or hesitant due to safety fears in traditional teaching.

5.2. Break Through the Resource Bottleneck and Realize the Sharing of High-Quality Experimental Resources

Due to the purchase cost of experimental equipment, space constraints and reagent storage conditions, it is difficult for many schools to offer all hazardous chemistry experiment courses completely. Some experiments that require special instruments, expensive reagents, or extreme reaction conditions often are only conducted perfunctorily through theoretical explanations or video demonstrations. VR technology breaks these resource barriers and transforms various dangerous experiments into reusable virtual resources through digital modeling. For example, experiments involving radioactive materials and catalytic reactions requiring high-temperature and high-pressure environments can be fully presented through VR technology. At the same time, virtual experimental resources can be shared across regions through the network platform, and schools in remote areas can also use VR equipment to carry out experimental projects that could not be completed originally, so as to promote the balanced distribution of educational resources and effectively narrow the experimental teaching gap caused by regional differences.

5.3. Innovate Teaching Mode to Significantly Improve Learning Effectiveness

The immersive learning experience brought by VR technology has completely changed the passive mode of traditional experimental teaching of "teacher demonstration and student onlookers". In the virtual laboratory, students feel as if they were in a real experimental scene. Through interactive devices such as handles, they can observe the experimental phenomenon 360 degrees and operate every step by themselves. For example, in the concentrated sulfuric acid dilution experiment, students can intuitively see the heat change and the simulation effect of liquid splash when the acid is mixed. This multisensory stimulation can strengthen memory far more than text or video. In addition, the parameter adjustability of VR system allows students to independently change reactant concentration, temperature and other conditions, observe the influence of different variables on experimental results, and transform confirmatory experiments into inquiry learning processes.

5.4. Stimulate the Spirit of Exploration and Cultivate Innovative Practical Ability

The "zero cost" nature of the virtual environment provides students with unlimited trial and error space. In traditional experiments, due to precious reagents and limited equipment, students often dare not try routine operations easily; In VR experiments, students can freely design experimental plans and explore different reaction paths. For example, in organic synthesis experiments, students can change the reaction conditions and adjust the ratio of reactants at will, and the system feeds back the experimental results in real time to help students establish the scientific thinking of "bold assumptions and careful verification". This open experimental environment not only cultivates students' practical ability, but also stimulates their innovative consciousness. Through repeated trial and error correction, students gradually master the methods of scientific inquiry, form the ability of independent thinking and problem solving, and lay the foundation for future scientific research.

5.5. Conform to Educational Trends and Promote the Digital Transformation of Teaching

Under the background of educational informatization 2.0 era, the application of VR technology is an important breakthrough to realize educational modernization. It not only innovates the teaching methods of dangerous chemical experiments, but also promotes the reform of the teaching mode of the whole chemistry discipline. By combining VR technology with smart classroom and online learning platform, a full-process digital teaching system including virtual preview before class, combination of virtual and real experiments during class, and cloud-based review after class can be built. At the same time, the operation data generated by VR experiments can be used to analyze students' learning

behaviors and provide a basis for personalized teaching. This technology-enabled teaching mode is not only a positive response to the Ministry of Education's policy of "promoting the deep integration of information technology and education and teaching", but also provides new ideas for the experimental teaching reform of other disciplines.

6. Summary and Outlook

Aiming at the core dilemma in traditional hazardous chemistry experiment teaching, this study deeply analyzes the unique advantages of VR technology. Based on three theories, a full-process VR experimental teaching mode covering "experimental preview-classroom teaching-review and assessment" is constructed. This model closely combines virtual experiment scenarios with actual teaching needs, which not only eliminates the potential safety hazards of dangerous experiments, but also guides students to change from passive learning to active inquiry through dynamic interaction, real-time feedback and personalized task design. Practice shows that this model has significantly improved students' experimental operation ability, safety awareness and knowledge understanding level. VR technology not only provides a new way to cultivate students' practical ability and scientific literacy, but also provides practical examples for implementing the policy requirements of the Ministry of Education to promote the integration of experimental teaching and emerging technologies.

Although VR technology has shown significant advantages in the teaching of hazardous chemistry experiments, there is still room for optimization. Future research can be deepened from three aspects. First, strengthen the integration design of VR experiments and real experiments by developing a hybrid teaching scheme that combines virtual and real, making up for the perceptual difference between the virtual environment and real operation. Second, explore the deep integration of AI technology and VR to realize personalized learning path recommendations and precise teaching interventions by intelligently analyzing students' operation data. Third, carry out long-term follow-up research to quantitatively evaluate the continuous impact of VR teaching on students' core literacy, such as scientific thinking and innovation ability. At the same time, it is necessary to pay attention to the standardization and sharing mechanism construction of VR teaching resource development, lower the application threshold, and promote its widespread popularization and sustainable development in the field of education.

In short, the application of VR technology in hazardous chemistry experimental teaching is an important practice in the digital transformation of education. It is necessary to continue to focus on the deep integration of technology and education, and take "safety, efficiency, and innovation" as the guide to promote the transformation of experimental teaching from "demonstration and verification" to the paradigm change of "inquiry and creativity".

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