Design of Immersive Virtual Reality (VR) Classroom Based on Embodied Cognition Theory and Analysis of Cognitive Transfer Effects

Yagang Mao
Department of International Communication and Cooperation, Zhengzhou Health College, Zhengzhou, Henan, China
**Corresponding author.*

Abstract. Guided by the theory of embodied cognition, this paper explores the design framework of immersive Virtual Reality (VR) classrooms and their impact on learners' cognitive transfer. Through theoretical analysis and practical research, it is found that VR learning environments based on multi-sensory interaction can significantly improve the efficiency of knowledge internalization and promote the development of cross-situational transfer abilities. The research results provide theoretical and practical references for embodied learning design in the field of educational technology. This paper aims to provide a scientific guiding framework for the development and application of VR educational products through systematic research, and to promote innovation and development in educational technology.

Keywords: Embodied Cognition; Immersive VR Classroom; Design Framework; Cognitive Transfer; Multi-Sensory Interaction.

1. Introduction

Traditional classroom teaching often focuses on the unilateral transmission of knowledge, neglecting the close connection between learners' bodily experiences and cognitive development. The separation of knowledge transmission from bodily experience leads to inadequate cultivation of learners' transfer abilities. Traditional teaching methods tend to emphasize the indoctrination of theoretical knowledge while neglecting the cultivation of practical abilities, making it difficult for learners to flexibly apply their learned knowledge when facing practical problems. Virtual Reality (VR) technology, by constructing immersive environments and supporting embodied interactions, provides learners with rich sensory experiences. This immersive environment can stimulate learners' interest in learning, improve learning efficiency, and align with the new paradigm of cognitive science. VR technology, with its unique sense of immersion and interactivity, offers a brand-new platform for education, enabling learners to engage in practical operations in virtual environments and enhance their learning experiences [1]. Embodied cognition theory emphasizes that cognition originates from the dynamic coupling between the body and the environment, meaning that cognitive processes involve not only brain activity but are also influenced by bodily states, sensory experiences, and environmental factors. This theory provides a new perspective for understanding cognitive processes and a theoretical foundation for the innovation of educational technologies. This study aims to expand the application boundaries of embodied cognition in educational technologies and verify the effectiveness of embodied cognition theory in VR classroom design through empirical research. This will help deepen the understanding of cognitive processes and promote the development of educational technology theory. It provides a design framework for the development of VR educational products, guiding developers on how to construct VR learning environments that conform to the principles of embodied cognition. By optimizing VR classroom design, it enhances learners' learning efficiency and transfer abilities, providing a scientific basis for educational practice. It fosters deep learning and the cultivation of transfer abilities, enabling learners to engage in practical operations in virtual environments, apply learned knowledge to different situations, and improve problem-solving skills. This contributes to the cultivation of learners' innovative thinking and practical abilities, enhancing the quality of education [2].

The core connotation of embodied cognition theory reveals the crucial roles of bodily perception, situational embeddedness and dynamic interaction, as well as the mirror neuron system in cognitive formation. Firstly, bodily perception is regarded as the cornerstone of cognitive formation. Embodied cognition theory emphasizes that learners' physical states and sensory experiences have a profound impact on their cognitive processes, thereby determining the acquisition and application of knowledge. For example, through tactile feedback, learners can more intuitively understand the shape and texture of objects. This hands-on experience not only enhances the intuitiveness of knowledge but also deepens memory, enabling learners to better grasp and apply what they have learned. Secondly, embodied cognition theory also emphasizes the situational embeddedness and dynamic interaction characteristics of cognition. The cognitive process does not exist in isolation but is closely linked to specific situations. Through continuous interaction with the environment, learners engage in trial and error and make adjustments, gradually constructing and refining their cognitive schemas. The discovery of the mirror neuron system provides a solid neuroscience foundation for embodied cognition theory. These special neurons can simulate the actions and behaviors of others, thereby understanding their intentions and emotions, further proving the importance of bodily movements in the cognitive process. The core connotation of embodied cognition theory not only reveals the foundational status of bodily perception in cognitive formation but also emphasizes the significant roles of situations, dynamic interactions, and the neuroscience foundation in the cognitive process [3].

2. Typical Application Cases

2.1 Virtual Laboratory

A notable application of VR technology in the field of education is the simulation of real laboratory environments. Through this technology, learners can perform various experimental operations in a virtual environment without the need to enter a physical laboratory. This immersive experience not only improves learners' experimental skills but also enhances their understanding of experimental principles and operational procedures. In the virtual laboratory, learners can freely explore, operate instruments, and observe experimental results. This interactivity and intuitiveness greatly enhance the learning outcomes. Historical Scene Reproduction: VR technology also enables learners to travel through time and space, experiencing historical events as if they were there. By simulating historical scenes, learners can more intuitively understand historical backgrounds, character relationships, and event developments, thereby deepening their knowledge of history. This immersive learning approach not only increases learners' interest but also helps them establish a more comprehensive and in-depth cognitive framework of history [4].

In VR chemistry experiments, learners can gain a deep understanding of chemical reaction principles and processes through molecular structure disassembly and visualization of reaction processes. This virtual experimental environment is not only safe and environmentally friendly but also provides rich sensory experiences and practical opportunities, helping to cultivate learners' experimental skills and scientific literacy [5]. Through VR technology, learners can experience a time-travel journey to ancient civilization sites, immersing themselves in the charm of historical culture. This immersive experience helps to stimulate learners' interest and deepen their understanding and memory of historical knowledge. At the same time, learners can also interact with virtual artifacts to learn about their historical backgrounds and cultural connotations.

In VR physics teaching, learners can deepen their understanding of physics concepts through interactive verification of mechanical principles. For example, learners can adjust experimental parameters in a virtual environment and observe the motion states of objects under different conditions, thereby understanding the application of mechanical principles. This virtual experimental environment not only provides abundant practical opportunities but also helps learners construct a complete cognitive schema [6].

2.2 Limitations of Existing Research

Despite significant progress in the application of VR technology in education, there are still some shortcomings. Firstly, the design of VR classrooms currently lacks systematic theoretical guidance. This results in varied design effectiveness in practical applications, making it difficult to achieve the intended teaching goals. To fully unleash the potential of VR technology, a comprehensive theoretical framework for classroom design needs to be established to guide educators in designing scientific and reasonable VR courses. Secondly, research on the cognitive transfer effect in VR environments is still relatively weak. Cognitive transfer refers to the ability of learners to transfer knowledge and skills acquired in one context to another. However, there is currently a lack of empirical research supporting the impact of VR environments on the cognitive transfer effect. This limits our comprehensive understanding of the effectiveness of VR technology in the field of education. To promote the in-depth application of VR technology in education, research on the cognitive transfer effect needs to be strengthened to explore how VR environments can facilitate learners' knowledge transfer and ability enhancement.

3. VR Classroom Design Framework Based on Embodied Cognition

3.1 Design Framework

When constructing a VR classroom design framework based on embodied cognition, we need to follow the following core design principles to ensure that learners can have a rich, natural, and effective learning experience in the virtual environment. Multimodal sensory integration is the foundation of the design framework. By integrating visual, auditory, tactile, and other sensory experiences, we can create a more three-dimensional and realistic learning environment for learners. In VR chemistry experiments, learners can not only observe molecular structures visually but also hear reaction sounds and even feel the vibration of the handle simulating the chemical reaction process through touch. This omnidirectional sensory experience helps deepen learners' understanding and memory of chemical principles, making them more engaged and focused during experimental operations. Natural interaction mechanisms are the key to the design framework. In VR classrooms, learners should be able to interact with the virtual environment through natural gestures, spatial movement, and other forms of bodily participation. This interaction method not only conforms to human natural behavior habits but also stimulates learners' interest and participation [7]. For example, in VR history education, learners can interact with virtual artifacts through gestures, feeling their texture and pattern, thereby gaining a more intuitive understanding of the background and connotation of historical culture. This natural interaction mechanism helps improve learners' learning efficiency and quality. Situational authenticity is an important guarantee for the design framework. By simulating physical laws and sociocultural situations, we can construct a virtual environment that is highly similar to the real world. This environment helps learners perform real operational practices in the virtual environment, improving their practical abilities. In VR physics teaching, learners can interactively verify mechanical principles in the virtual environment, observing changes in experimental results by continuously adjusting experimental parameters. This authentic situational experience helps deepen learners' understanding and application abilities of mechanical principles. Cognitive scaffolding is the supporting structure of the design framework. By designing dynamic difficulty adjustment and instant feedback systems, we can provide personalized cognitive support for learners. Dynamic difficulty adjustment can automatically adjust the difficulty of tasks based on learners' learning progress and ability levels, ensuring that they can learn at an appropriate difficulty level. The instant feedback system can provide real-time feedback on learners' learning outcomes and existing problems, helping them adjust their learning strategies and methods in a timely manner. This cognitive scaffolding helps enhance learners' autonomous learning abilities and problem-solving skills [8].

3.2 Technical Implementation Path

When constructing a VR classroom based on embodied cognition, hardware configuration, software development, and AI assistance are three indispensable technical implementation elements. To provide a high-quality immersive experience, we use high-performance VR hardware devices. The HTC Vive Pro 2 headset, with its high resolution and low latency, brings learners clear and smooth visual effects. At the same time, the addition of a full-body motion capture system allows every subtle movement of the learner to be accurately captured, achieving natural interaction with the virtual environment. This precise capture and feedback mechanism not only enhances learners' immersion but also provides them with a richer and more realistic interactive experience. In terms of software development, we choose to develop using the Unity engine combined with the PhysX physics engine. The Unity engine, with its powerful graphics rendering and physics simulation capabilities, constructs a realistic virtual environment for us. In this environment, learners can interact with objects as they would in the real world, feeling real physical feedback [9]. The PhysX physics engine provides high-precision physics simulation, ensuring that the behavior of objects in the virtual environment conforms to physical laws, thereby enhancing the authenticity and credibility of the virtual environment. To further improve learners' learning experience and effectiveness, we introduce a personalized guidance algorithm based on learning behavior data. This algorithm identifies learners' learning styles and interests by analyzing their learning behavior data, such as learning progress, answer accuracy, and study duration. Based on this data, the algorithm can provide customized learning resources and tasks for learners, helping them learn more efficiently. Furthermore, the algorithm can provide instant feedback and suggestions based on learners' performance, helping them adjust their learning strategies and methods in a timely manner. This personalized guidance approach not only improves learners' motivation and participation but also provides them with more flexible and diverse learning paths. Through high-performance VR hardware devices, the combination of the Unity engine and PhysX physics engine, and a personalized guidance algorithm based on learning behavior data, we have successfully constructed a technical implementation framework for a VR classroom based on embodied cognition. This framework provides learners with a high-quality immersive experience, a realistic virtual environment, and personalized learning guidance, effectively promoting their learning and development [10].

4. Conclusion

This study, based on the theory of embodied cognition, deeply explores the potential of VR technology in education and constructs a VR classroom design framework based on embodied cognition. By integrating core design principles such as multimodal sensory integration, natural interaction mechanisms, situational authenticity, and cognitive scaffolding, we provide learners with a rich, natural, and effective learning environment. Practical cases show that this design framework can significantly improve learners' learning efficiency and transfer abilities. Looking forward, we will continue to deepen our research on the theory of embodied cognition and further optimize the VR classroom design framework. At the same time, we will actively explore the application of new technologies such as AI in the field of education, providing learners with more precise learning support through personalized guidance algorithms. We believe that with the continuous advancement of technology and the increasing improvement of theory, VR education will usher in a new era, bringing learners richer, more diverse, and efficient learning experiences. This will powerfully promote the innovation of educational practice and cultivate more talents with innovative thinking and practical abilities.

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