Investigating the Effect of Immersive VR on Conceptual Knowledge and Procedural Knowledge Transfer

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***Abstract*—Promoting knowledge transfer and developing students' complex problem-solving skills are important goals in today's education. The use of immersive virtual reality in teaching and learning has shown great potential to achieve this goal. This study used a quasi-experimental research method, with a video group as the control group, to investigate the effect of the immersive virtual reality learning environment on learners' conceptual and procedural knowledge transfer. The results found that learners in the immersive virtual reality learning environment scored significantly higher than those in the video group on the conceptual knowledge transfer and procedural knowledge transfer test. These results suggest that immersive virtual reality is more advantageous than video learning in facilitating knowledge transfer.**

***Keywords*—immersive virtual reality, knowledge transfer, conceptual knowledge, procedural knowledge**

I. Introduction

The goal of education is to promote learning, and the purpose of learning is transfer. In today's knowledge explosion, it is impossible to deliver all knowledge to students in school, and it is only through transfer of learning that students can adapt to the ever-changing society. Reference [1] defined transfer as the application of acquired knowledge in a new way or different context. According to [2], transfer occurs whenever previously learned knowledge influences current learning or when a currently solved problem influences the way a new problem is solved. As can be seen, knowledge transfer can be understood as the process of mobilizing, recognizing and/or adapting in a specific context and then to be applied in different contexts.

Learning transfer is an old topic as well as a new one. As an old topic, the core of learning transfer lies in explaining and understanding the phenomenon of learning transfer and investigating the nature of transfer and its rules. Since the introduction of learning transfer, educators and psychologists around the world have put forward a number of basic theories of learning transfer, including the earliest formal discipline theory based on functional psychology, the identical element theory, and the generalization theory. Many researchers have also analyzed and explored the mechanisms and factors of learning transfer from the perspectives of different learning theories (e.g., behaviorism, cognitivism, constructivism, and connectionism). As emerging information technologies (e.g., big data, artificial intelligence and virtual reality) continue to be used in education, researchers have begun to focus on how to use these technologies to help learners achieve learning transfer, especially virtual reality [3]. Virtual reality has many important affordances, such as providing learners with realistic learning situations, hands-on learning opportunities, self-paced learning, flexible learning methods and immediate personalized feedback. These affordances can provide conditions for learners to realize learning transfer to the greatest extent [4]. Although virtual reality has great potential to facilitate students' knowledge from the perspective of its characteristics and transfer theory, there is little research on the use of virtual reality to facilitate knowledge transfer, and it has not been proven through empirical studies. Based on this, this study utilizes a quasi-experimental research method, using video learning as the control group, to examine the role of the immersive virtual reality (IVR) in influencing student knowledge transfer.

II. Literature Review

A. Conceptual and procedural knowledge

Conceptual knowledge and procedural knowledge are two important categories of knowledge within the knowledge dimension of Bloom' s revised taxonomy of cognitive targets. Reference [5] defined procedural knowledge as "knowledge of how to do things". This includes knowledge and criteria for the use of skills, algorithms, techniques and methods, and these together constitute "procedure". Essentially, procedural knowledge is the application of learned procedures to solve a problem or complete a task. Conceptual knowledge, the knowledge about "why", describes the relationship between the basic elements of the whole structure and indicates the internal relationship and system structure of the organizational form of knowledge in a certain discipline field. Learning conceptual knowledge requires the involvement of higher order thinking skills such as comprehension, analysis, evaluation, and creativity.

Reference [6] states that the application of procedural knowledge involves two cognitive processes: executing and implementing. For tasks that are familiar to the learner, the familiar context provides the learner with appropriate cues to choose the right procedure, and the learner simply performs the procedure. When faced with an unfamiliar task, the learner has difficulty immediately deciding which procedure to apply and must first understand the problem before determining the range of procedures to choose. In other words, understanding conceptual knowledge is a prerequisite for applying procedural knowledge when learners are completing unfamiliar tasks. The relationship between conceptual and procedural knowledge is not divorced, but complement each other. Reference [7]'s study demonstrated improving learners conceptual understanding of what they are learning will support their selection of appropriate problem-solving procedures and thus improve procedural skills. Other studies have shown that students' improving procedural knowledge is accompanied by an increase in their problem-solving

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experience, thereby reducing misunderstandings of relevant concepts and promoting the construction of conceptual knowledge[8]. Therefore, understanding the nature of conceptual and procedural knowledge and their interactions is important to this study.

B. VR-based study on knowledge transfer

Current research on virtual reality-based knowledge transfer has demonstrated the potential of virtual reality to help learners construct conceptual and procedural knowledge that can be applied in the real world. Firstly, knowledge transfer is closely linked to the context in which it is acquired in the real world. Reference [9] noted that knowledge is more transferable when students acquire it in the meaningful contexts. Virtual reality can not only provide learners with the virtual learning environment that resembles the task context but can also combine the virtual learning environment with a transferable context to trigger the same behavior and thinking as in the real situation. More importantly, the immersive, interactive, and imaginative nature of virtual learning environments can facilitate active processing of task-related elements and help learners to construct internal representations. When faced with similar situations, the index-based internal representations help learners to easily extract knowledge and apply it in the desired context. Reference [10] found that virtual reality-based situated learning activities help learners to apply their newly acquired knowledge and skills to real-world problem solving compared to traditional teaching approaches.

In addition, embodied cognition theory emphasizes that the integration of cognition and the body and the interaction between the body and the external environment can promote the depth of cognitive engagement. Reference [11] showed that the process of bodily movement can facilitate the processing and understanding of abstract concepts. Compared to traditional teaching methods, virtual reality supports learners' natural interactions with learning objects through body movement and sensory input; allows cognition to be rooted in physical action and experience to be constructed through embodied interaction; and thus realizes the effective integration of physical embodiment and intentional embodiment [12]. It has also been found that when learners interact with virtual environments using their own bodies, they are able to reduce the amount of cognitive resources used for higher-order cognitive processes such as imagination and thinking. The embodied interactions allow limited cognitive resources for deeper processing of learning content, thus enabling knowledge transfer from the virtual to the real environment. Reference [13] found that providing learners with embodied interaction in a virtual learning environment not only increases learners' self-efficacy and engagement but also their performance on transfer tests. In addition, the development of new technologies (e.g., spatial positioning, mot ion capture, and haptic perception) can enable greater learner involvement and provide learners with a higher level of user control, thus facilitating learning transfer.

In summary, this study sought to explore the following research questions: (1) Does the IVR learning environment facilitate conceptual knowledge transfer for learners compared to the video learning approach? (2) Does the IVR learning environment facilitate the transfer of learners' procedural knowledge compared to the video learning approach?

III. METHODS

A. Participants

In this study, a total of 40 students (31 boys and 9 girls) in the first grade of a middle school in Chongqing were selected and randomly assigned to the experimental group (IVR group) and the control group (VD group). In the end, there were 20 subjects in the IVR group, including 15 boys and 5 girls, and 20 subjects in the VD group, including 16 boys and 4 girls.

B. Experimental Materials

1) IVR application

The aim of the "Investigating the Law of Current in Series Circuits" IVR experiment is to enable students to understand the characteristics of series circuits, master the law of current in series circuits, skillfully design and connect experimental circuits, and correctly use an ammeter to measure current. The IVR experiment was developed based on the Unity 3D platform and the virtual reality device chosen was the HTC Vive VR glasses. The 3D model used in the experiment is very similar with the actual experimental equipment and meets the needs of the experiment.

The "Investigating the Law of Current in Series Circuits" IVR experiment can be divided into two parts: experimental apparatus instruction and hands-on experimental process, as shown in Figure 1 and Figure 2. When learners enter the IVR environment, they are first introduced to the content of the experiment: knowledge about series circuits, the equipment (i.e., bulb, switch, power supply, ammeter, and wires), and cautions for connecting the circuit and the experiment process. During this process, learners do not need to do anything but watch the text and listen to the audio recording. In the hands-on part of the experiment, learners used the handheld controllers to manipulate the corresponding equipment to complete the circuit connections and current measurements. The process was as follows: (1) learners select the correct set of four light bulbs for the experiment; (2) they select the correct equipment for the rest of the experiment; (3) they use wires to connect each piece of equipment to form a series circuit and ensure the correct ammeter range is selected; (4) they close the switch, read the current and record it; (5) they use the ammeter to measure the remaining two parts of the circuit and record the current; and (6) they draw conclusions from the current data at the three locations.

Fig 1. Experimental apparatus instruction

Fig 2. Hands-on experimental process

2) Instructional video

For the recording of instructional videos exploring the law of current in series circuits, this study adopted the form of screen capture. The specific screening process was as follows. First, the screen recording software was prepared. Bandi screen recording software was used in this study, and the experimental videos were set to be recorded in full screen. Next, the screening began. Experimental assistants familiar with the experiment completed the experiment step by step according to the experimental steps. In order to record all relevant learning content presented in the VR experiment and ensure that learners will not miss any information, three experimental assistants were asked to record six videos twice respectively in the study. Finally, the best video was selected. According to whether the information was presented comprehensively, whether the recorded screen was skewed or shaky, and whether there were too many errors or steps out of order in the operation process, the best VR experiment video was selected from the six videos.

C. Pre-test Questionnaire

The pre-test questionnaire mainly included students' demographic information (only included gender) and priori knowledge questionnaire. The age of the students was not measured as the subjects selected for the experiment were all first year junior high school students. The priori knowledge level for "Investigating the Law of Current in Series Circuits" was measured with five questions, including circuit course experiences, activities, and knowledge related to circuit connections. For example, "What do you know about connecting series circuits?" and "What do you know about currents and their measurement?". Students were assessed on a self-report basis, scoring from lowest to highest (1 point for strongly disagree to 5 points for strongly agree). Five questions were summed to give an a priori knowledge score, which was used to verify whether there were differences in a priori knowledge between the two groups. Self-reporting was used instead of a knowledge test to measure the level of students' priori knowledge because of the potential for the knowledge test to create a "test effect" by focusing the subject's attention on specific learning content during the experiment [14].

D. Knowledge Transfer Test

The knowledge transfer tests in this study consisted of conceptual knowledge transfer test and procedural knowledge transfer test.

1) Conceptual knowledge: This study used test questions to measure the effectiveness of conceptual knowledge transfer for both groups. The questions consisted of two multiple-choice questions and two circuit design questions totaling 10 points. The questions chosen aligned with the educational objectives of the section and involved applying theoretical knowledge of series circuit connections and the current laws of series circuits to solve practical problems. One point was awarded for each correct answer to the two multiple choice questions, for a total of two points. The circuit design questions required students to not only connect the circuit diagram correctly but also to complete the corresponding textual explanation. Four points are awarded for each question, with two points for correct circuit design and two points for correct textual explanation; otherwise, no marks were awarded.

2) Procedural knowledge: In order to measure the effectiveness of procedural knowledge transfer between the two groups, this study arranged for two groups of students to complete a hands-on experiment on "Investigating the Law of Current in Series Circuits" using real experimental equipment. The experimental equipment was identical to the equipment used in the IVR experiment and instructional videos. In addition, this study selected Time to Completion (TTC)[15], Number of Error (NOE)[16], and Number of Help (NOH)[17], which are the most commonly used indicators for evaluating procedural knowledge transfer in current research. TTC refers to the total time spent from the start of the experiment to the final completion of the experiment. NOE refers to the number of errors made by the students during the hands-on process and was counted by the experimental assistants based on a list of incorrect actions. The list of errors developed with the participation of the relevant subject teachers contains a total of eight error actions, such as not disconnecting the switch during circuit connection and reversing the + and - terminals of the ammeter. If a mistake was made during this process, the experimental assistant told the students about the mistake five seconds after the relevant operation was completed. The students were also provided with the correct instructions. If students forgot the next step in the process of connecting a circuit, they could ask the experimental assistants for help. The number of times student sought help was called NOH.

E. Experimental Procedures

In the preparation phase of the experiment, the experimental assistants gave basic introduction of the experiment to the participating students and randomly assigned the 40 students into IVR and VD groups. Before the experiment started, students were required to complete a pre-test questionnaire, which included demographic information and priori knowledge of series circuits. Then, the two groups of students performed the experiment simultaneously in different areas. In the IVR group, the experimental assistants brought the students the HTC Vive head-mounted display and instructed them on how to use the controllers to manipulate the virtual objects. To avoid negative learning effects due to improper operation of the IVR device, students could ask the experiment assistants about the operation of the IVR device during the learning process. Unlike the IVR group, students in the VD group wore headphones to watch the instructional video on a 14-inch laptop computer. The experiment time for both groups of students was 30 minutes. In the end, students were required to take the conceptual knowledge transfer test and procedural knowledge transfer test. The whole process was video-recorded for subsequent analysis.

IV. Results

A. Pre-test Questionnaire Results

Prior to answering the research questions, we first investigated whether there were significant differences between the two experimental groups in terms of basic characteristics. Independent samples *t*-tests indicated no significant differences between the two groups in terms of the prior knowledge, $t\ (38) = 1.27$, $p = 0.213$. A chi-square test also indicated that the groups did not differ significantly in the proportion of male and female students, $\chi^2(1, N = 40) = 0.143$, $p = 0.705$. Therefore, there was no significant difference between the IVR and VD groups in terms of priori knowledge and gender proportion in this study.

B. Conceptual Knowledge Transfer Results

The research question (1): Did the immersive VR facilitate students' conceptual knowledge transfer compared to the video learning? To answer this question, data from the conceptual knowledge transfer tests of the two groups was analyzed using independent samples *t*-tests. As shown in Table I, learners in the IVR group scored higher on the conceptual knowledge transfer test($M = 6.85$, $SD = 1.05$) than learners in the VD group($M = 6.05$, $SD = 0.83$), and the difference between the two groups was statistically significant $t(38) = 2.694$, $p = 0.01$. The results suggest that, compared to video learning, IVR can significantly promote learner' conceptual knowledge transfer.

C. Procedural Knowledge Transfer Results

Research question (2): did immersive virtual reality facilitate procedural knowledge transfer for students compared to the video learning? As can be seen from Table II, the mean TTC of IVR group ($M = 236.25$s, $SD = 48.23$) decreased by 12.7% during the real hands-on manipulation compared the VD group ($M = 270.60$s, $SD = 47.93$), and the difference between the two groups was statistically significant, $t\ (38) = -2.259$, $p = 0.03$. The mean NOE of IVR group ($M = 1.60$, $SD = 0.68$) decreased by 36% during the real hands-on manipulation compared to the students in the VD group ($M = 2.50$, $SD = 1.00$), and the results showed a significant difference $t\ (38) = -3.327$, $p = 0.002$. The mean NOH of IVR group ($M = 0.65$, $SD = 0.88$) decreased by 50% during the real hands-on manipulation compared to the students in the VD group ($M = 1.30$, $SD = 1.12$), and the difference between the two groups was statistically significant $t(38) = -2.035$, $p = 0.049$. It was evident that the students' behavioral performance of the IVR group was better than that of the VD group in the procedural knowledge transfer test. Specifically, the IVR group could not only complete the experimental task more quickly but also independently and successfully complete the experimental task. Therefore, immersive virtual reality could better promote the procedural knowledge transfer.

TABLE I.

Results of conceptual knowledge transfer between IVR group and VD group

	IVR		VD		Df	t	Sig.
	M	*SD*	*M*	*SD*			
Conceptual Knowledge	6.85	1.04	6.05	0.83	38	2.694	0.010**

*p<0.05,**p<0.01, ***p<0.001

TABLE II.

Results of Procedural knowledge transfer between IVR group and VD group

	IVR		VD		Df	t	Sig.
	M	*SD*	*M*	*SD*			
TTC	236.25	48.23	270.60	47.93	38	-2.259	0.030*
NOE	1.60	0.68	2.50	1.00	38	-3.327	0.002**
NOH	0.65	0.88	1.30	1.12	38	-2.035	0.049*

V. Discussion

Consistent with the findings of most previous studies that investigate the effectiveness of IVR on facilitating students' procedural knowledge transfer [18], the results of this study showed students in the IVR group scored significantly higher on the procedural knowledge transfer test than students in the video group. Some previous studies have also found a positive media effect that IVR outperformed less immersive media on procedural knowledge transfer tests [19]. Reference [20] argued that IVR can provide learners with great interactivity and agency, facilitating students to actively control the pace of learning and thus engage in a high level of generative processes. In addition, compared to one-way interactive video learning, IVR learning environments allow for two-way interaction between the learner and the learning content. For example, immersive learning environments provide rich hands-on opportunities and "learning by doing" activities, adapt learned procedures based on feedback, which facilitates the learning of procedural knowledge [21]. What's more, the interactive characteristic of VR helps to activate the learner's multiple senses, thereby improving learning outcomes. The reason for this is that the multi-sensory involvement helps learners to acquire more perceptual information related to the learning content and to build multimodal representations. It also activates the previous cognitive structures and effectively connects current knowledge with prior knowledge, helping learners to internalize relevant concepts and laying the foundation for subsequent transfer.

This study also found that IVR significantly improved students' conceptual knowledge transfer compared to video learning, which is quite different from the results of previous studies [22 – 24]. In previous studies, it was noted that IVR learning environments could cause higher cognitive overload for students than the video. IVR provides learners with a higher level of immersion and greater control than desktop and semi-immersive virtual reality, but to achieve this, immersive virtual reality requires a more complex environment design and more perceptual channels' interaction. At the same time, due to the complexity of the virtual environment, students pay more attention to the attractive virtual learning environment than the learning content during learning process, resulting in higher extraneous cognitive load. According to working memory theory, the cognitive resources of the students is limited. Higher extraneous cognitive load will lead to less germane cognitive load which makes it impossible to achieve deep processing of the learning content. Considering the above issues, this study applied the dual-channel principle, the signal principle, and the immediate feedback principle to reduce the extraneous cognitive load of students when designing and developing the virtual circuit experiment. These design principles have been shown to be effective in reducing the extraneous cognitive load of students and even promoting relevant cognitive load when used in the design of IVR learning environments. In addition, students in the IVR group were trained to use the virtual reality device before the experiment to minimize the extraneous cognitive load on the learners. Therefore, students in the IVR group would have more cognitive resources to process the learning content, thereby improving the effect of conceptual knowledge transfer.

Furthermore, the different IVR devices used in this study and in previous studies also affected students' conceptual knowledge transfer. The IVR devices used in the study by Reference[22-24]were the Samsung GearVR and Lenovo Mirage Solo. These two types of virtual reality devices are also known as mobile virtual reality (MVR) due to their portability and the fact that they don’t need to be connected to external hardware for graphics processing or motion perception. Although MVR is also referred to as IVR, its limited graphics processing power and limited three degrees of freedom for interaction make it far less immersive and interactive than fully immersive virtual reality(e.g., HTC Vive, Oculus Rift, and PlayStation VR) [25]. The HTC Vive fully IVR device used in this study has higher resolution, refresh rate, field of view, and lower latency, which greatly improves the sensory immersion experience of students. It also provides six degrees of freedom of interaction to achieve more flexible and free navigation and manipulation, allowing students to participate more physically in the experimental process; promoting students' embodied interactions; and thus, effectively facilitating learners' conceptual knowledge transfer. First, the multisensory stimulation provided by IVR can help students acquire perceptual information related to the learning content using multiple sensory channels and build multimodal representations, which provides students with a cognitive foundation for understanding abstract concepts. What’s more, the IVR scenario activates the original cognitive structure and more effectively connects the currently learned concepts with previous knowledge, which helps students internalize relevant concepts and achieve deep learning [26]. Secondly, the six-degree-of-freedom interaction can support students' more flexible and direct bodily manipulation of external representations of learning content; give students real intuitive feelings and manipulation experiences; stimulate frequent interactions between learners' body, mind and IVR learning environment; promote students' embodied cognition; and realize the complex construction of conceptual knowledge from low to high level and from concrete to abstract.

VI. CONCLUSION

This study investigated the effect of the IVR on conceptual and procedural knowledge transfer, and found that students learning with IVR facilitated the transfer of both procedural knowledge and conceptual knowledge transfer compared to video learning. There are still some shortcomings in this study. For example, it only tested students’ conceptual and procedural knowledge transfer perspective but did not consider the interaction between conceptual and procedural knowledge transfer. Secondly, the knowledge transfer test was only a test of near transfer and could not verify the effect of IVR on far transfer. In future research, the impact of the IVR learning environments on students' knowledge transfer will be explored in greater depth with the help of new measurement methods (e.g., EEG,eye-tracking) to realize a greater role for IVR technology in education.

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