

Impact of Concept Map–Integrated Spherical Video-Based Virtual Reality (SVVR) Learning on Students' Performance and Retention in Fault Diagnosis Training

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ABSTRACT

This study investigates the impact of integrating concept maps with spherical video-based virtual reality (SVVR) on learning achievement and retention in equipment fault diagnosis training. Using a quasi-experimental design, the experimental group used a SVVR model with concept maps, while the control group used a traditional SVVR model. Results showed no significant difference in learning achievement between groups. Surprisingly, the control group performed significantly better in learning retention, which contradicts prior research. The paper discusses this finding and offers suggestions for future research and pedagogical applications, highlighting the importance of managing cognitive load when integrating multiple learning tools.

Keywords: Virtual Reality, Spherical Video-based Virtual Reality (SVVR), Concept Map, Computer Troubleshooting, Learning Achievement, Knowledge Retention

1. INTRODUCTION

In recent years, virtual reality (VR) technology has been widely applied in various educational fields, aiming to provide learners with an immersive and appropriate learning environment that helps them deeply understand the definitions, concepts, processes, and principles of abstract knowledge ^[1]. Through VR technology, learners can engage in learning activities in a near-real context, which not only helps in connecting and integrating knowledge but also improves knowledge retention and transfer effectiveness ^[2] ^[3]. Furthermore, the sense of presence and interactivity brought by a real-world context can effectively stimulate learning interest and enhance learning motivation. In professional training or workplace training settings, the application of VR can not only reduce the cost of physical teaching resources but also improve the efficiency and effectiveness of training ^[4]. However, despite the numerous advantages of traditional VR in education, its high development cost and technical barriers have become major factors limiting its widespread adoption in basic education settings ^[5]. For this reason, researchers have proposed spherical video-based virtual reality (SVVR) as an alternative. SVVR utilizes an image-based environment composed of 360-degree videos or panoramic images, which not only retains the immersive characteristics of VR learning but also has lower technical costs and development difficulty. It can also provide a more realistic learning experience through real image materials ^[6] ^[7].

Despite the many advantages of applying VR to education, its practical implementation still faces several challenges. First, many virtual learning systems may provide excessive information, leading to high cognitive load for learners in the virtual environment ^[8]. For example, SVVR's high degree of realism and rich sensory input, while helpful for creating an immersive experience, may also make it difficult for learners to effectively integrate the large and diverse amount of information obtained from the environment with their existing knowledge structures ^[9]. Additionally, some studies have indicated that VR teaching models may not necessarily be superior to traditional teaching methods in terms of learning effectiveness, suggesting that VR intervention does not guarantee an improvement in learning outcomes ^[10]. Therefore, to unleash the potential of SVVR in teaching, it should be combined with

appropriate instructional strategies to guide students in performing meaningful knowledge construction and transformation within the virtual environment [11].

In digital learning environments, the use of cognitive tools can help learners effectively organize knowledge and reduce the cognitive load caused by complex learning content [12] [13]. Among these, concept maps are widely regarded as an effective cognitive tool for structuring knowledge. They can not only strengthen students' cognitive processes [14] [15] but also help in cultivating their logical thinking, reasoning ability, and autonomous learning skills [16]. Related research also points out that the application of concept maps can not only improve students' learning achievement but also enhance their questioning performance, promoting deeper learning [17]. For example, Chen et al. integrated concept maps into augmented reality (AR) instruction for a fifth-grade natural science course, and the results showed that students using the AR learning system combined with concept maps performed significantly better than those who only used AR [18]. Despite previous research exploring the effectiveness of concept maps and immersive technology in teaching, studies on the integrated application of "concept maps and spherical video-based virtual reality (SVVR)" are still relatively limited, especially in the context of professional skills training.

In conclusion, this study attempts to propose an SVVR teaching model integrated with concept maps, hoping to assist learners in effectively integrating information and constructing understanding through a structured knowledge organization mechanism, thereby improving learning achievement and retention performance. To verify the effectiveness of this model, this study uses a computer equipment fault diagnosis course as the instructional context to explore the following two research questions:

- (1) Compared to learners using a general SVVR learning model, do learners who use an SVVR learning model with integrated concept maps have a significant advantage in learning achievement?
- (2) Compared to learners using a general SVVR learning model, do learners who use an SVVR learning model with integrated concept maps have a significant advantage in learning retention performance?

The results of this study will help to understand the application potential of cognitive tools in immersive learning environments and can serve as an important reference for future design of SVVR instructional materials or immersive teaching strategies.

2. METHODOLOGY

2.1 System and Experimental Design

This study utilized the Uptale platform to develop a "Computer Fault Diagnosis Learning System" and applied it to teaching activities for high school and vocational school students. The system architecture primarily consists of two main parts: database management and the instructional activity interface (as shown in Figure 1).

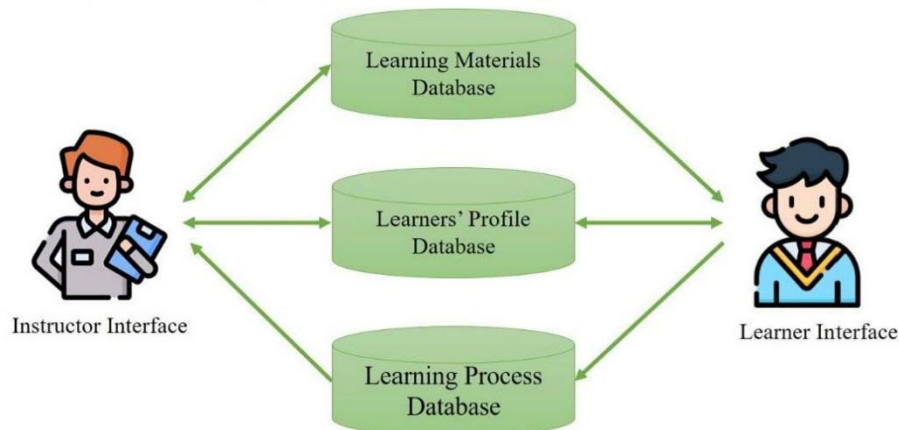


Figure 1. System Architecture Diagram

Note: The diagram shows the Instructor Interface and Learner Interface each connected bidirectionally to three central databases: the Learning Materials Database, Learners' Profile Database, and Learning Process Database.

In terms of database management, the system contains three types of databases: a Learning Material Database, which is managed and revised by the instructor, containing learning materials, worksheets, and the necessary assets for building the system; a Learner Database, which stores basic information of the learners participating in the experiment; and a Learning Log Database, which records the learners' operation and interaction history within the system.

The instructional content is centered on "computer hardware fault diagnosis" and is designed with one main scene and four sub-scenes. Learners can freely enter any instructional scene by clicking on the "door" icon in the main scene, and they can return to it repeatedly for learning. Each instructional scene contains four types of learning materials: "Audio," "Indicator Lights," "Screens and Functions," and "Text." Upon entering a scene, learners can click on the "Hardware Device" icon to study the material or click on the "Question Mark" icon to practice the unit quiz (as shown in Figure 2).

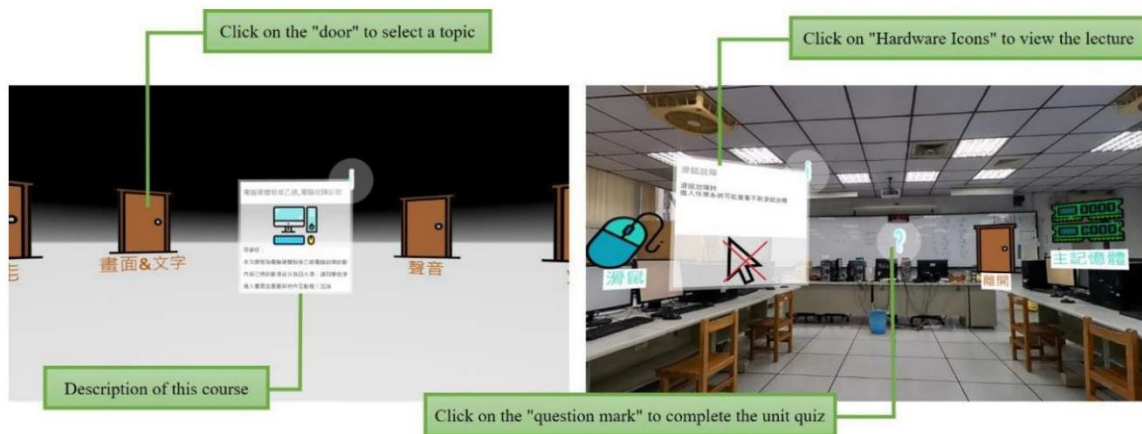


Figure 2. SVVR Learning Scene

Note: The figure shows two screenshots of the SVVR interface: a scene-selection screen where learners click on a "door" to select a topic, and a 360-degree classroom view where learners click on hardware icons to view the lecture or click a question-mark icon to complete the unit quiz.

All learners used tablet computers to operate the spherical video-based virtual reality (SVVR) system. This study divided the participants into two groups: the experimental group, which used the SVVR learning model integrated with concept maps, where learners organized and integrated learned knowledge using paper-based concept maps while experiencing SVVR (as shown in Figure 3); and the control group, which used a general SVVR learning model, where learners were free to record, summarize, or annotate their learned content but were not provided with any structured graphical aids.

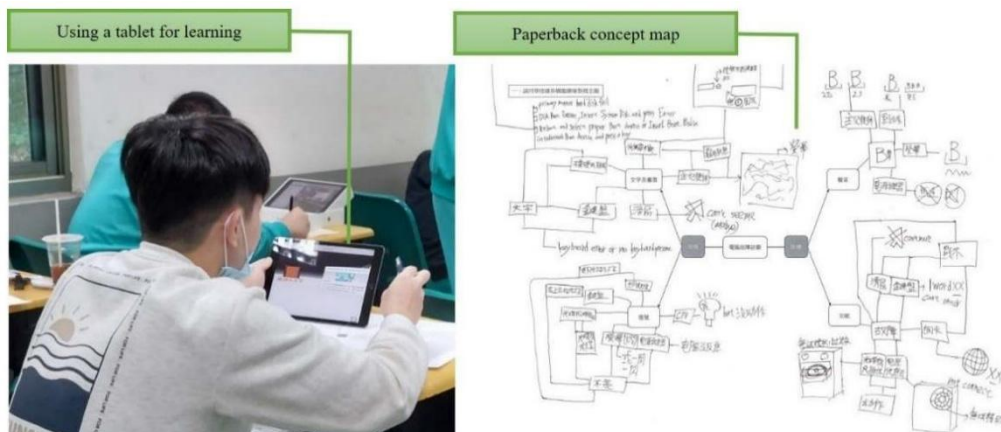


Figure 3. Learners Operating the System on a Tablet and Drawing a Paper-Based Concept Map

2.2 Participants

This study adopted a quasi-experimental design. The participants were 63 second-year students from two classes in the Department of Information Technology at a public vocational high school in northern Taiwan. A total of 57 valid questionnaires were collected, including 55 male and 2 female participants, with an average age of 17. The two classes were randomly assigned to either the experimental or control group. The experimental group consisted of 29 students who received the virtual reality learning model integrated with concept maps, while the control group consisted of 28 students who received the general virtual reality learning model. The instructional content was "computer fault diagnosis," and none of the students had previously used an SVVR system to learn this topic. To eliminate the confounding variable of teacher's teaching style, the same teacher with over five years of teaching experience in electronics and electrical engineering groups delivered all the instruction.

2.3 Experimental Procedure

The experimental procedure of this study is shown in Figure 4. Before the formal experiment began, both the experimental and control groups took a 15-minute pre-test on basic computer hardware knowledge. After the pre-test, both groups received a 10-minute SVVR operation tutorial and practiced using the system on tablet computers. Subsequently, both groups entered the main instructional phase, which focused on computer fault diagnosis and lasted for 60 minutes. The experimental group used the SVVR learning model integrated with concept maps, while the control group used the SVVR learning model without concept maps. After the course, all students completed a post-test on computer hardware fault diagnosis, which lasted about 15 minutes. One week after the instruction, both groups took a delayed test to assess their knowledge of computer hardware fault diagnosis, which also lasted 15 minutes. After all experimental procedures were completed, the research team conducted interviews with a portion of the students to further understand their learning process and experiences.

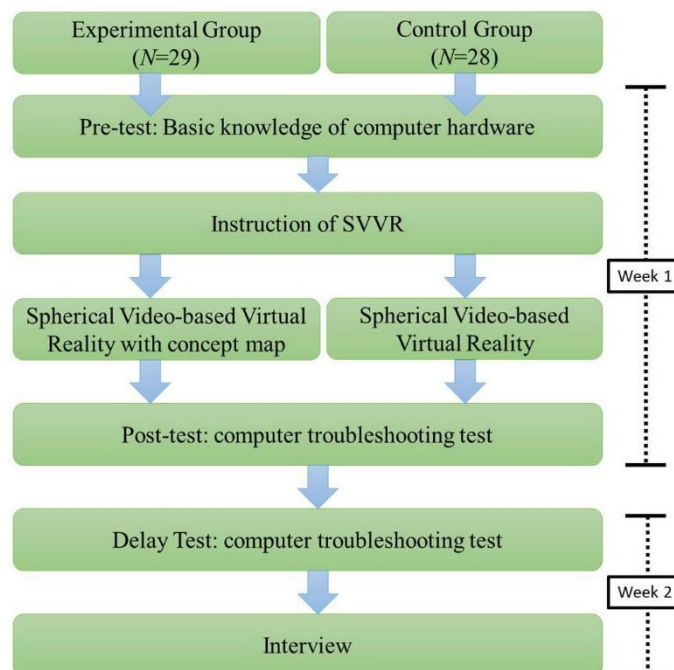


Figure 4. Research Flowchart

2.4 Measurement Tools

The measurement tools used in this study included three tests: a pre-test on basic computer hardware

knowledge, a post-test on computer fault diagnosis, and a delayed test on computer fault diagnosis. All test questions were prepared by a full-time teacher with over five years of teaching experience. The pre-test was designed to evaluate students' understanding of basic computer hardware knowledge, consisting of 10 multiple-choice questions with a total score of 100. The post-test was used to assess students' knowledge acquisition after learning the computer hardware fault diagnosis unit. The question types included 7 item sets and 2 multiple-choice questions. Each item set contained several options, and points were accumulated based on the correct answers selected by the students, with a total score of 100. The delayed test was used to measure students' knowledge retention one week after the instruction, consisting of 20 multiple-choice questions with a total score of 100. The pre-test, post-test, and delayed test in this study differed in question types and number of questions. The pre-test used simple multiple-choice questions to measure students' familiarity with basic knowledge. The post-test was an immediate assessment after the course; its question types were designed to be more relevant to fault diagnosis tasks, using item sets to test students' understanding and application of practical problems. The delayed test focused on knowledge retention and was designed with multiple-choice questions to reduce the burden of answering and to facilitate its administration one week after the experiment.

3. RESULTS

This study performed an Analysis of Covariance (ANCOVA) to statistically analyze the learning achievement of the experimental and control groups, controlling for the influence of pre-test differences.

3.1 Learning Achievement

According to the Levene's test results, the homogeneity of variance of the scores between the two groups was not significant ($F = 1.81, p = .184 > .05$). And the assumption of homogeneity of regression test between the group and the covariate was not statistically significant ($F_{(1,53)} = 0.241, p = .626$). As shown in Table 1, the ANCOVA results showed no significant difference in learning achievement between the experimental and control groups ($F = 0.06, p = .812 > .05$). This result indicates that the virtual reality learning model integrated with concept maps was not significantly superior to the virtual reality-only learning model in terms of learning achievement.

Table 1. ANCOVA Results for Learning Achievement

Group	N	Mean	SD	Adjust mean	SE	F
EG	29	78.6	10.6	78.6	1.93	0.06
CG	28	79.3	11.6	79.3	1.97	

3.2 Learning Retention

This study conducted an Analysis of Covariance (ANCOVA) to analyze the learning retention of the experimental and control groups, controlling for the influence of pre-test differences. Based on the Levene's test results, the homogeneity of variance of the data for both groups was not significant ($F = 1.24, p = .271 > .05$). And the assumption of homogeneity of regression test between the group and the covariate was not statistically significant ($F_{(1,53)} = 0.990, p = .324$). As shown in Table 2, the ANCOVA results revealed a significant difference in learning retention between the two groups ($F = 4.48, p = .039 < .05$). This result shows that learners who used the virtual reality-only learning model performed significantly better in learning retention than those who used the virtual reality learning model integrated with concept maps.

Table 2. ANCOVA Results for Learning Retention

Group	N	Mean	SD	Adjust mean	SE	F	η^2
EG	29	57.1	16.2	57.3	2.30	4.48*	.077
CG	28	64.5	12.8	64.2	2.34		

3.3 Interview Results

To explore the impact of the spherical video-based virtual reality and concept map learning strategies on learners, this study conducted open-ended interviews with 57 participants. The interview data were analyzed using grounded theory^[19], with the following analysis steps: (1) Coding: classifying the data and constructing the meaning of the classifications; (2) Memoing: recording learner feedback and experiences; (3) Synthesizing and summarizing: consolidating the data to extract key factors to understand the meaning of the data.

Based on the interviews, most learners had a positive view of the spherical video-based virtual reality learning model, focusing on the following two aspects:

(1) Increased Learning Motivation

Learners generally stated that the virtual reality learning method was novel and interesting, which helped increase their learning interest. An experimental group learner (E15) said, *"It's easier to understand and makes students interested in learning."* A control group learner (C16) also mentioned, *"It's better at raising my learning interest."* This shows that the virtual reality learning environment is helpful in stimulating learning interest.

(2) Provided a Convenient Learning Method

Some learners pointed out that compared to traditional teaching materials, virtual reality materials save the need for physical resources and improve learning efficiency. An experimental group learner (E35) felt, *"This method allows for learning in a more resource-saving way."* A control group learner (C28) mentioned, *"It's much more practical and effective than a blackboard."* This study inferred that learners considered this model to be more convenient and practical than traditional learning methods.

Regarding the use of concept maps, the opinions of the experimental group learners can be summarized into two main points:

(1) Helps with Memory and Understanding

Some learners believed that concept maps helped with knowledge integration and memory consolidation. Learner (E13) pointed out, *"Compared to giving students a pre-organized chart, letting students organize it themselves gives them more memorable points, and because they organized it themselves, they can understand the whole document more quickly."* Another learner (E19) said, *"I think learning in this special way makes it easier to understand and remember what's being taught."* This shows that concept maps promoted students' active knowledge construction and comprehension processes.

(2) Caused Time Pressure and Load

However, many learners also reported that their lack of experience using concept maps, combined with the paper-based method, made the learning process time-consuming and challenging. Learner (E29) said, *"Drawing a concept map on the computer is more efficient; using pen and paper takes too much time."* Learner (E36) also pointed out, *"Spent too much time copying content, didn't know what to write."* This indicates that under time constraints, paper-based concept maps may cause additional cognitive load, affecting learning efficiency.

4. DISCUSSION

This study investigated whether a virtual reality learning model integrated with concept maps could enhance learning achievement and retention in a computer fault diagnosis course for vocational high school students. The initial hypothesis was that the concept map strategy would help learners more effectively organize and internalize knowledge, leading to better outcomes than those who used virtual reality alone. However, the results showed that the control group (SVVR only) performed better than the experimental group (SVVR with concept maps) in terms of learning retention. The following sections discuss these two variables: learning achievement and learning retention.

The ANCOVA analysis showed no significant difference in learning achievement between the

experimental and control groups, which was contrary to our initial expectation. Previous research often points out that virtual reality helps improve learning effectiveness, especially due to its immersive and interactive nature ^[20]. However, in this study, both groups of students used the same SVVR materials and had the same opportunities for viewing and interaction, so there was no difference in the basic learning experience. Moreover, most students were using SVVR for the first time. ^[21] suggested that VR has a "novelty effect" for students, which may temporarily boost their engagement and attention, potentially affecting the overall learning performance of both groups and thus diminishing the difference in instructional strategies.

Surprisingly, the control group performed significantly better on the learning retention test than the experimental group. This finding contradicts previous research that suggests concept maps are beneficial for knowledge structuring and long-term memory ^[22] ^[23]. The interview data revealed that experimental group students widely found it challenging to create a paper-based concept map immediately after the SVVR experience. They were unable to focus on understanding the material, and the frequent switching between the tablet and pen-and-paper caused attention to be divided, leading to excessive cognitive load. The "split-attention effect" proposed by ^[24] states that requiring learners to mentally integrate information from different sources can increase extraneous cognitive load. Furthermore, ^[25] proposed that virtual reality must satisfy the "3I" principles, with "immersion" being a key factor. Offloading the concept map task outside the VR experience may have reduced students' focus and sense of immersion in the VR content, thereby affecting their learning outcomes. A further analysis of student interviews indicated that some experimental group students lacked experience using concept maps for learning, making it difficult for them to quickly grasp how to effectively organize knowledge. Student B29 said, *"Drawing a concept map on the computer is more efficient; using pen and paper takes too much time."* Student E36 mentioned, *"I spent too much time copying content and didn't know what to write."* We infer that learners in the experimental group, without well-established concept mapping experience, had to expend extra effort to adapt and think, which increased their learning burden. Clark and Mayer also pointed out that humans have a limited capacity for processing information, and if instructional design fails to properly arrange the presentation of information, it may hinder learners from engaging in meaningful learning ^[26].

In conclusion, the results of this study show that concept maps and virtual reality have different learning strategy characteristics, and improper design can lead to resource competition and interference. Concept mapping is a tool for knowledge organization and integration, requiring static thinking and planning, whereas virtual reality emphasizes interaction and exploration. When learners switch back and forth between these two strategies without proper guidance or integration, cognitive interference is likely to occur. For future studies seeking to integrate concept maps with virtual reality, it is recommended to refer to Mayer and Moreno's "spatial contiguity principle" ^[27] by embedding the concept map function directly into the SVVR system to reduce the cost of learners switching between different media. This would prevent the auxiliary learning tool from becoming a burden and undermining the original learning benefits, as noted by Charsky and Ressler ^[28].

This study has the following limitations: First, the participants were high school students from a vocational school in northern Taiwan, so the findings cannot be generalized to other regions or age groups. Second, the sample size of this study was small. Additionally, all participants were from information-related fields, which may have given them a certain affinity for computer hardware knowledge, potentially affecting their technical adaptability and perception of concept map use during the learning process. Future research should expand to include students from different backgrounds to examine the differences in the strategy's effects among heterogeneous groups.

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