International Journal of Evaluation and Research in Education (IJERE)
Vol. 13, No. 5, October 2024, pp. 3239~3247
ISSN: 2252-8822, DOI: 10.11591/ijere.v13i5.28109

The impact of video-based virtual reality training on critical thinking and cognitive load

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Article Info

Article history:

Received Jul 20, 2023
Revised Dec 4, 2023
Accepted Jan 25, 2024

Keywords:

Cognitive load
Critical thinking
Distance learning
Higher education
Mental abilities
SV-IVR

ABSTRACT

Online learning, including in higher education, is an active part of the modern educational landscape. Spherical video-based immersive virtual reality (SV-IVR) is useful in this field. This study aimed to determine the impact of teaching with the use of SV-IVR on the critical thinking and cognitive load of 140 students. The findings of the study revealed that students exhibited low levels of mental effort and mental load based on the observed indicators. Compared to the traditional teaching method, the SV-IVR model had a better effect on improving students' critical thinking skills. The findings can help teachers develop new learning models using video-based virtual reality.

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1. INTRODUCTION

More and more universities are choosing distance learning and using various online learning platforms, such as videoconferencing, e-mail, and massive open online courses [1]. This situation caused certain problems in learning for students. For example, students usually study at home rather than in institutions, which decreases attention in some of them. Sometimes, they open the live broadcast of the teacher and, at the same time, play from another mobile device. As a result, their attention is lower than during face-to-face classes [2].

Scientific and technological progress has led to modifications and achievements in teaching and learning methods [3]. For example, the introduction of virtual reality (VR) in education has drastically changed the teaching and study of many subjects. Currently, there is an opportunity to use VR to effectively demonstrate situational effects that are usually difficult to demonstrate in the classroom. However, the creation and preparation of materials and equipment for 3D VR are complicated and time-consuming. Therefore, its implementation will require more human and material resources [4]. This study employed spherical video-based immersive virtual reality (SV-IVR) to provide a more authentic representation of learning environments. Compared with 3D VR, SV-IVR is convenient, simple, and intuitive [5]. The work with the system requires only a smartphone and cardboard glasses. This technology can address numerous educational needs, ranging from the development of instructional materials to student engagement [6].

The utilization of the technology mentioned above in education represents a relatively novel research area. Therefore, in this study, the educational curriculum was modified using SV-IVR. As a result, a cyclic learning process based on level design was established.

2. LITERATURE REVIEW

2.1. Virtual reality and spherical video-based immersive virtual reality

VR is a technology that can provide an immersive experience using three-dimensional modeling of various scenes that simulate natural environments [7], thus fostering a sense of presence within the virtual location [8], [9]. VR can be divided into three categories: i) virtual desktop (low-immersive VR desktop environment) uses 3D computer modelling to create a three-dimensional object that users can view and use with a computer, mobile phone, and tablet [10]; ii) cave automatic virtual environment (CAVE) provides a panoramic sensory experience in a confined space [11]; and iii) full immersion VR that provides an immersive experience with VR equipment [11].

The incorporation of VR within educational contexts entails a variety of negative factors. Several studies [12], [13] have provided evidence indicating the potential to induce dizziness among students when utilizing VR technology. Additionally, the high cost and implementation complexity serve as drawbacks [14]. Some instructors may lack the necessary expertise to create VR materials, posing challenges to their integration [14]. Consequently, it is crucial to identify affordable ways of utilizing VR.

SV-VR is a recently developed technology [4], [15]. It is more convenient and requires only a panoramic camera, such as Insta 360, to create educational materials [16]. Immersive video allows the viewer to watch 360° videos and adjust the desired content and angle of inclination [10]. SV-IVR also solves the problem of over-reliance on 3D modelling for VR [7], [17], [18]. Thus, the convenience, interactivity, and contextual experience of SV-IVR demonstrate great potential in the educational sector [16]. Figure 1 shows the main differences between 3D VR and SV-IVR.

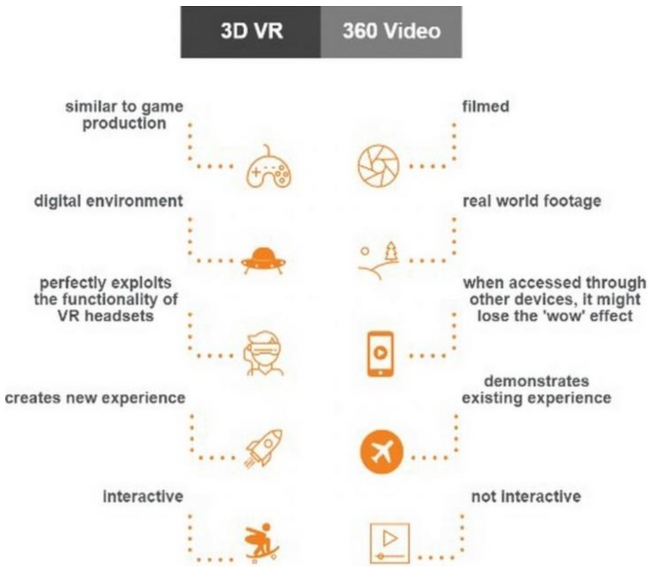

Figure 1. The main differences between 3D VR and SV-IVR

2.2. Immersive effect

Immersive technologies blur the line between the real and virtual worlds and allow users to experience a sense of immersion [19]. As a result, it is possible to improve the learning experience, promote cooperation, and increase creativity and engagement. Moreover, according to another study, multisensory coordinated cooperation, as well as visual, auditory, and tactile signals, can enhance this immersion [20]. At the same time, well-designed VR materials and content can facilitate immersion in the learning process. Previous research has also concluded that an important feature of VR is an immersive effect, which empowers users [21]. Naturally, the immersive experience itself can have negative implications. During a VR experience, proper attention should be given to the intense fear and anger that immersion can provoke [19]. Additionally, dizziness and other symptoms of discomfort have been observed [20], [22].

2.3. Impact of virtual reality technologies on critical thinking

Critical thinking encompasses the cognitive faculties of analysis, evaluation, and synthesis, as Paul and Elder [23] described. Critical thinking skills can be defined as the ability to test ideas when solving problems, analyze and evaluate thinking, draw conclusions regarding problems and facts, and form opinions [24]–[26]. The results of a study confirm that VR can develop the critical thinking skills of students [25]. One of the approaches to critical thinking development is the choice of the right model [27]. A VR tool is a technology that allows users to easily interact with a computer simulation of an environment or event via a smartphone. The implementation of this model does not require face-to-face meetings. However, with the help of such platforms as Zoom and Google Meet, it is possible to establish communication between teachers and students [28].

2.4. Problem statement

The motivation for this study was to help students improve their attitude toward learning, develop their critical-thinking skills, and promote their involvement in the educational process. This study aimed to investigate the effects of using SV-IVR for learning on students' critical thinking skills and cognitive load. The tasks were as follows: i) to conduct a student survey to identify the effect of SV-IVR on their cognitive load and attitude to learning and ii) using the testing method, to collect data on the student's level of critical thinking, to identify the impact of SV-IVR on this indicator.

3. METHOD

The researchers employed a quasi-experimental study design wherein the participants were divided into two groups: a control group and an experimental group. It used a pre-test and post-test to assess the effects of using SV-IVR for learning on students' critical thinking skills and cognitive load. The reliability of the methodology was thoroughly tested using Cronbach's alpha (a statistical indicator of internal consistency or reliability of a psychometric instrument).

3.1. Participants

The researchers enrolled a total of 140 medical students from I.M. Sechenov First Moscow State Medical University, who were divided into two groups: i) experimental – 70 students (36 females and 34 males) and ii) control – 70 students (44 females and 26 males). The participants were divided into groups using a random allocation method. The age range of the participants was between 18 and 20 years. In the experimental group, students received an SV-IVR learning experience, while the control group followed a traditional instructional approach. Both groups were instructed by the same instructor. Participants in the experimental group were provided with Google Cardboard. The learning process took place online.

3.2. Development of spherical video-based immersive virtual reality learning system

The EduVenture VR platform served as a development tool [29]. Teachers could use their computers to create educational materials on the EduVenture VR platform. The system included a material editing module, a database module, and the SV-IVR training module.

3.3. Learning process

A cyclic learning process was devised, whereby students were required to take tests on the topics they had studied within a specified timeframe. The inability to pass any of the tests impeded their advancement to subsequent topics, compelling them to revisit and reinforce their understanding of the subject matter until they achieved success in the corresponding test. Moreover, students were provided with an interactive experience wherein teachers posed thought-provoking questions and aided students in formulating responses. Subsequently, students were required to record their answers within the virtual environment and upload them to an internal database. It was expected that this interaction would encourage the students to be proactive and active in receiving multi-level feedback and reflections as well as forward them to high-level thinking.

3.4. Experimental procedure

At baseline, the students of both groups were asked to take preliminary tests, which took approximately 60 minutes. At that time, they were not aware of their assignment to groups, and to maintain the accuracy of the experiment, they did not know about the two learning styles. In addition, the teacher provided a live webcast and a brief introduction to the course content, training system, instructions for use, and precautions. Throughout the experimental phase, the participants comprising the experimental group employed SV-IVR technology alongside the utilization of Google Cardboard as an instructional resource for their learning experiences After using the system, the SV-IVR context was displayed on a smartphone. In contrast, the control group employed a conventional technology-based learning approach. This approach implied that PPT presentations, videos, and images were displayed on a computer screen. The teachers conducted an 80-minute online learning session. After the lesson, all students completed a post-training test and a questionnaire.

3.5. Research tools

To understand how students experience cognitive load, the authors used a cognitive load questionnaire adapted to the context of this study [29]. The questionnaire has two scales: mental effort and mental load (Tables 1 and 2). To assess students' perception of the use of SV-IVR, the study used a questionnaire developed by Jong *et al.* [29] and modified for this study. The questionnaire showed attitudes toward the personal digital assistant (PDA). The questionnaire demonstrated good reliability, with a Cronbach's alpha coefficient of 0.82. This indicates that the responses to the questions in this questionnaire exhibit a high degree of internal consistency and homogeneity.

The Cornell critical thinking test (CCTT), level X [30], was used to measure students' critical-thinking skills. The CCTT-X test consists of 78 multiple-choice items that take 50 minutes to complete. Incorrect and correct answers are scored as '0' and '1', respectively, which give a total test score of 0 to 78. The test's reliability has been established [30], and within the sample of this study, it exhibited favorable validity with a Cronbach's alpha coefficient of 0.88. This attests to the high internal reliability of the test, signifying that the test effectively measures students' critical thinking skills.

Table 1. Items for studying cognitive load

A1. Mental effort	A2. Mental load
1. When I study, I have to understand the content of the educational material with higher mental effort.	1. When I study, the way the educational material is explained causes a lot of stress for me.
2. When I study, I have to spend a lot of mental effort to make sense of the augmented information.	2. When I study, I cannot focus on the educational material.

Table 2. Topics to explore the attitude to learning

Topic	Statements
C1. Perceived control	1. I think the SV-IVR system is easy to use.
	2. I can learn how to use the SV-IVR system in a short time.
	3. The SV-IVR system is difficult for me.*
	4. I need an experienced person to be by my side when I learn to use SV-IVR.*
C2. Perceived utility	1. I think SV-IVR is helpful for my learning.
	2. SV-IVR can help me understand the content better.
	3. Learning with SV-IVR helps generate more ideas.
	4. Learning with SV-IVR is an alternative learning method.
C3. Behavior in traditional learning	1. After learning with SV-IVR, I want to get a deeper understanding of the content of the educational course.
	2. After learning with SV-IVR, I developed an interest in the educational course.
	3. I hope to read more information on the topic of the educational course.
	4. SV-IVR-based learning did not contribute to the development of my interest in the educational course.*
	5. Questions regarding the educational course were not attractive to me, even though I learned with the SV-IVR.*
C4. Behavior in SV-IVR learning	1. I hope that I will have more opportunities to study with SV-IVR.
	2. I tend to study using SV-IVR on other topics in the future.
	3. I expect there are more applications of SV-IVR in education.
	4. I have more intentions to learn with SV-IVR.

*Evaluation in reverse.

3.6. Statistical analysis

For a broader understanding of cognitive load and students' attitudes towards learning using SV-IVR, their scores on questionnaire scales were analyzed using paired t-tests and intra-subject ANOVA. Before analyzing the results of the critical thinking test, the authors tested the normality and homogeneity of the data. They applied the Kolmogorov-Smirnov and Levene's tests, respectively. In addition, ANCOVA and the least significant difference test were used.

3.7. Limitations

Time of learning (6 sessions 80 minutes each), sample size, factors of gender, age, and learning styles of students. The design of the study included a control group that did not receive VR-based intervention. This group continued its standard curriculum, which could vary for each participant and potentially immeasurably affect the level of their cognitive load.

4. RESULTS
4.1. Cognitive load and attitude to learning

Data on cognitive load (Table 3) showed that students' levels of mental effort (M=2.24, SD=0.79) and mental load (M=2.21, SD=0.76) were generally low. There was no significant difference between the indicators of mental effort and mental load (t=0.66, P>0.05). In other words, students did not experience excessive cognitive load when learning information during training. The indicators related to the cognitive efforts of students (mental effort) and the required cognitive skills (mental load) in the learning process were similar.

As for the student attitudes towards learning with the SV-IVR, Table 3 presents the differences between the attitude questionnaire scales. More specifically, students' perceived utility scores were significantly higher than perceived control scores (t=-3.97, P<0.001). It means that the students in this study believed that the SV-IVR use could be more beneficial to their learning, rather than emphasizing the SV-IVR ease of use. Upon further examination of students' intention to learn, the researchers found that their behavior in SV-IVR learning scores was significantly higher than behavior in traditional learning scores (t=-3.33, p<0.001).

4.2. Critical thinking

The researchers analyzed the testing results of students' critical-thinking skills for normality and uniformity (Table 4). The purpose of this analysis was to assess the normality and homogeneity of the data, which is a crucial step in understanding the distribution and characteristics of these skills among the student population. The analysis of critical thinking skills holds significant importance as it serves as the foundation for subsequent research and interpretation of results, facilitating a comprehensive understanding of the conclusions.

Table 4 presents the distribution of scores in critical thinking among the participating students. The data in this table indicate that these scores adhere to a normal distribution and exhibit a high level of homogeneity. The level of significance does not exceed 0.05. This statistical analysis serves as a crucial foundation for further exploring the impact of the instructional model on students' critical thinking skills, as it ensures the reliability and stability of the data. Table 5 demonstrates the influence of the learning model on students' critical-thinking skills.

Table 5 provides information about the differences between the learning models (F calculated =100.487, p-value =0.000; p-value <α (α=0.05)). Thus, it was hypothesized that the SV-IVR learning model affects students' critical thinking skills. After the hypothesis was confirmed the least significant difference tests were performed (Table 6).

Table 3. Paired t-tests for surveys on cognitive load and attitude to learning

Scale Cognitive load:	Meaning	Standard deviation	T-value
Mental effort	2.24	0.79	0.66
Mental load	2.21	0.76	
Attitude:			
Perceived control	3.75	0.73	-3.97***
Perceived utility	3.96	0.51	
Behavior in traditional learning	3.58	0.66	-3.33***
Behavior in SV-IVR learning	3.77	0.61	

***P<0.001

Table 4. Normality and homogeneity of the results of the critical-thinking skills test

	Normality		Homogeneity	
	N	Sig.	Skor Levene test	Sig.
Pre-test	70	0.000	1.064	0.367
Post-test	70	0.173	1.182	0.322

Table 5. ANCOVA results (critical-thinking skills)

Source	Type III sum of squares	The number of degrees of freedom	Mean square	F	Sig.
Adjusted model	18603.433*	4	4650.857	75.704	0.000
Interception	34594.703	1	34594.700	563.132	0.000
Xcritical	38.350	1	38.350	0.623	0.432
Class	18519.967	3	6173.320	100.487	0.000
Error	5713.256	91	61.432		
Total	503159.653	99			
Adjusted total	24316.687	96			

R squared =0.765 (Adjusted R squared =0.755)

Table 6. The least significant difference test results

Group	Pre-test	Post-test	Difference	Increase	Corrected item - total	LSD notation
Control	23.394	48.271	24.877	106.34%	48.144	a
Experimental	22.424	73.182	50.758	226.35%	72.962	b

The test found a significant difference between the experimental model and the traditional method: the scores for the experimental and control groups were 73.18 and 48.27, respectively. This result suggests that the use of SV-IVR was more effective than traditional training. The mean scores of the experimental and control groups for basic clarification were 47% and 35%, for decision-making reasons: 55% and 40%, and for inference: 50% and 40%, respectively. Scores for advanced clearing were 55% and 36%, for guessing and integration: 70% and 55%, and for strategic and tactical clearing: 75% and 60%, respectively.

5. DISCUSSION

The findings revealed that compared to traditional instruction, SV-IVR-based learning could enhance critical thinking, aligning with previous research. For instance, studies have demonstrated that the quality of integrated hybrid learning in a virtual laboratory was highly favorable, and a significant difference in critical thinking skills was observed between participants in the control and experimental groups [31]. An improvement in students' critical-thinking skills as a result of using VR learning models has been determined [32]. The results showed that VR tools can improve students' critical thinking skills. Nevertheless, some authors also indicated contradictory results. In the study, they used one pre-test and one post-test to determine the impact of virtual simulation on students' critical thinking and self-learning skills [33]. There were no significant differences in the scores for critical thinking and independent learning before and after the virtual simulation.

This study did not find any significant differences in the cognitive load of the two groups, which correlates with some studies. Some scientists evaluated the potential benefits of immersive technologies using head-mounted displays [34]–[36]. Reports on cognitive load did not differ depending on the visualization technology. Another investigation yielded discernible variations in the cognitive load experienced by students [14]. Spherical video-based virtual reality (SVVR) in education holds the potential to revitalize students' learning approaches, enhance the traditional instructional process, and deepen comprehension of educational content [10]. Given the constraints imposed by experimental methods, measurement techniques, and the duration of the experiment, data about cognitive load in this study may be subject to certain limitations. These issues will be thoroughly studied in the future.

Multiple studies have been conducted, affirming the beneficial influence of VR on students' cognitive processes and engagement, as documented by [37]–[39]. The researchers used an online 3D VR platform and experimented to evaluate the effectiveness of student learning based on Bloom's level of cognitive complexity [38]. The results show that learning in the virtual world contributes to the development of more complex thinking skills. The analysis revealed that students respond positively to the virtual learning environment due to its distinctive attributes of immersion, user-friendliness, and available support options.

In a study, participants were assigned to one of three teaching methods: traditional (textbook format), VR, or video [37]. Participants in the traditional and VR format had higher overall scores compared to participants in the video format. Participants also showed more successful memorization in the VR environment compared to the results of participants in the traditional and video environments. At the same time, participants in the VR environment demonstrated higher engagement than participants in other environments. Overall, VR represented an improved learning experience compared to traditional and video learning methods.

6. CONCLUSION

The results of this study are as follows. The indicators of mental effort and mental load were lower during SV-IVR learning, with no significant difference between the two variables. Behavioral indicators in SV-IVR learning were significantly higher than in traditional learning. Compared to the traditional teaching method, the SV-IVR model had a better effect on improving students' critical thinking skills. Thus, the main contribution of this research is a developed educational system that facilitates teaching and learning through SV-IVR, which is more accessible and user-friendly than traditional VR-based training. The obtained research results hold significant practical implications for educational practices and may influence the development of educational programs and policies. Educational programs can be revised and adapted to incorporate the SV-IVR method.

The findings of this study can serve as a basis for the creation of new courses and programs that utilize this technology. The mentioned research results may impact the formulation of policy decisions and the allocation of investments in the field of education. Governments and educational organizations may express interest in funding and advancing SV-IVR technologies in educational institutions. Considering the positive outcomes of the research, they may view this as a pivotal investment in enhancing the quality of education. Investments may also encompass the development of necessary infrastructure to support SV-IVR, such as improving network connectivity and providing essential equipment in educational institutions. Since the implementation of SV-IVR requires pedagogical competencies, teacher training and the preparation of other educational professionals may be necessary for the effective utilization of this technology. Future research may use educational experiments to study the impact of this technology on various training programs. In addition, it is also important to consider the influence of various devices. It is worth noting that future research should consider the novelty factor and how to address problems associated with it. Since this technology is recently developed its novelty may affect the actual perception of students.

ACKNOWLEDGEMENTS

The authors are grateful to the Middle East University, Amman, Jordan and Kazan Federal University Strategic Academic Leadership Program (Priority-2030) for the financial support.

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