A study on the application and effects of virtual reality in teaching intravenous injection

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Abstract. Intravenous injection is an important nursing technique, and this study developed and evaluated a virtual reality intravenous injection teaching system. One hundred and twenty-five undergraduate nursing and other medical students were selected to learn for IV injection using Meta Quest 2 and structural equation modeling was used to analyze students' emotions, immersion, and cognitive engagement during the learning process. The results showed that students had high immersion and cognitive input when using virtual reality (β=0.511, p<0.01), but the immersion of virtual reality could not enhance students' active learning willingness (β=0.127, p>0.05), and students' learning willingness was still affected by subjective emotional experience (β=0.723, p<0.01). Virtual reality technology can effectively improve students' cognitive engagement in clinical teaching, which has good feasibility, but we need to control students' fatigue level when teaching to play a better effect.

Keywords: component; Virtual Reality; Meta Quest 2; Learning systems; IV injection.

1 Introduction

Peripheral IVs are a common invasive procedure encountered by junior healthcare professionals and can be challenging for beginners[1]. In the traditional teaching process, students first learn about the procedure through lectures by the instructor, and then try it out on a medical model or on patients and classmates[2]. Yu, JL et al. concluded that visual demonstrations and hands-on training with feedback were effective in reducing learning time, minimising mishandling and increasing confidence in skill mastery when learning such simple but important medical technologies. Therefore, it is essential to propose a technically sound and well-simulated solution to assist with IV training.

In recent years, virtual reality technology, digital information systems, and physical environmental interaction have been increasingly used in the field of education[3]. Virtual reality is currently used in education for various purposes. For instance, Fong et al. used virtual reality tools for stroke rehabilitation[4]; Ghaednia et al. used virtual reality tools to support spinal surgery[5]. Virtual reality tools have been shown to be effective for supporting learning[6]. However, few studies have focused on the impact

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of virtual reality on learners' affective experience and cognitive engagement. Further research is needed to enhance the effectiveness of virtual reality as an aid to education by investigating the cognitive engagement and emotional experience of learners using virtual reality technology tools.

This project examines the impact of virtual reality technology on learners' cognitive engagement and emotions in the context of clinical intravenous teaching. The study involved 125 pre-nursing and general university students and investigated variables such as immersion, perceived enjoyment, cognitive engagement, and behavioural intentions.

2 Method

2.1 Research model and hypotheses

Perceived enjoyment is a pleasurable emotional experience that learners have about using the system itself. Previous research has shown that the use of immersive learning tools in instructional environments can enhance the learning experience. Students who find the system engaging are more likely to be motivated to learn. Immersion is the state of being mentally present, which includes a sense of engagement, concentration, and presence in the virtual system[7]. Studies indicate that immersion can lead to more profound impressions and engaging cognitive elements. Immersion in nature has a direct impact on the user's motivation and influences the construction of the student's knowledge system[8].

Some argue that learning is only meaningful when learners consciously engage in cognitive processes. They suggest that a high level of cognitive engagement requires significant attention and endurance from the learner[9] ,while leading to better learning outcomes. Behavioural intention in this study represents the user's intention to use the virtual reality medical education system for learning, and the user usually puts more effort into the learning content that he/she is willing to do.

In summary, we developed a framework based on metaphors, as shown in Figure 1. The framework was used to illustrate the causal relationships in VR-based learning environments and guide our research design and evaluation of how VR improves learning. We formulated five hypotheses:

H1: The user's perceived enjoyment has a positive impact on their behavioral intention.

H2: The user's immersion in the VR system environment has a positive impact on their perceived enjoyment.

H3: The user's immersion in the VR system environment has a positive impact on their cognitive engagement.

H4: The user's immersion in the VR system environment has a positive impact on their behavioral intention.

H9: When using the VR medical education system, the user's behavioral intention has a positive impact on their cognitive engagement.

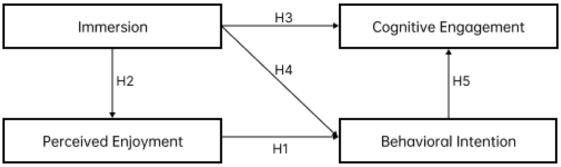

Fig. 1. Conceptual framework of subjective experience in mixed reality learning environments.

2.2 Participants

This study gathered 125 participants between December 2022 and June 2022 at the Clinical Skills Training Centre of Sun Yat-sen University and the School of Medicine of South China University of Technology. The age range of the participants was between 18 and 25 years. All participants were free from cognitive impairment or any other diseases that could have affected the experiment. Prior to the experiment, participants signed an informed consent form and had no prior knowledge of its purpose.

2.3 Materials

A virtual reality learning environment was created using the Unity 3D game engine (Unity Technology, San Francisco, CA, USA). C# scripts were used to configure the interaction logic and system framework. The teaching software was reviewed by experts from the Clinical Skills Training Centre of Sun Yat-sen University before being deployed on the Meta Quest 2 device. The software simulates the real environment of injection through joystick and virtual reality technology (depicted in Figure 2). To complete the training, students must wear the Meta Quest 2 helmet and follow thirteen steps, from preoperative preparation to sealing and fixation of the tube on the model arm of the virtual scene. Interaction with the system is achieved through gestures and voice. The system automatically grades the student's performance and uploads it to the instructor.

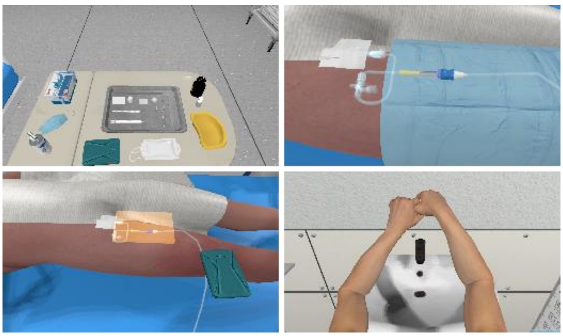

Fig. 2. System and User Interface.

2.4 Procedure

All participants will undergo one session of intravenous (IV) learning. The experiment will take place in a standard hospital bed area. Participants will first receive the Meta Quest 2 device and a 10-minute hands-on instruction to become familiar with the virtual reality (VR) device. They will then be guided by an instructor to learn using the VR IV teaching system and practice injections in a virtual scenario. At the end of the course, participants will complete a system experience scale.

Statistical Analysis

The study's questionnaire measured six constructs of the conceptual framework using a total of 16 questions. The questionnaire included sub-variables related to both subjective experience, such as perceived enjoyment and immersion, and learning outcomes, such as cognitive engagement and behavioural intention. The questions used in this study were adapted from validated studies and measured on a 7-point Likert scale ranging from (1) 'very much does not meet' to (7) 'very much meets'. The measurement and structural models were evaluated using structural equation modelling (SEM). The analysis included testing for convergent validity, discriminant validity, and model fit using AMOS 18.0. The research hypotheses were also tested.

3 Results

3.1 Measurement model

When conducting an SEM study, the initial step is to analyze the structural validity. In this study, we conducted a confirmatory factor analysis (CFA) on all study dimensions. The standardized factor loading for all eight dimensions of the model ranged from 0.65 to 0.9 and were all significant. All dimensions have good internal consistency with a component reliability (CR) greater than 0.7 and mean variance extractions ranging from 0.64 to 0.75, all of which are greater than the suggested criteria of 0.5 by Hair[10],Fornell and Larcker[11]. Table 1 presents the results of the measurement model analysis, confirming the reliability and convergent validity of all dimensions.

Table 1. Parameters of the significant test and reliability

Factor	Item	S.E.	t	P	Std.	SMC	CR	AVE
Behavioral Intention	BI1				.783	.613	.894	.680
	BI2	.117	10.714	***	.911	.830		
	BI3	.119	8.177	***	.720	.518		
	BI4	.124	10.281	***	.870	.757		

Cognitive Engagement	CE1				.889	.790	.925	.756
	CE2	.073	13.681	***	.878	.771		
	CE3	.068	13.718	***	.879	.773		
	CE4	.073	12.309	***	.830	.689		
Immersion	IM1				.794	.630	.900	.644
	IM2	.109	10.112	***	.852	.726		
	IM3	.113	8.463	***	.738	.545		
	IM4	.107	9.014	***	.777	.604		
	IM5	.117	10.018	***	.846	.716		
Perceived Enjoyment	PE1				.838	.702	.912	.722
	PE2	.088	10.637	***	.828	.686		
	PE3	.088	11.344	***	.865	.748		
	PE4	.091	11.356	***	.866	.750		

This study employed discriminate validity analysis to test for differences in correlation between dimensions by comparing the square root of the average variance extracted (AVE) with the Pearson correlation coefficient. The results indicate a considerable degree of discriminate validity between the dimensions, as the open root values of AVE for the dimensions were all greater than the corresponding Pearson's correlation coefficients. The specific data can be found in Table 2.

Table 2. Composite reliability, convergence validity, and discriminate validity

	CR	**AVE**	**IM**	**PE**	**BI**	**CE**
IM	.900	.644	.802			
PE	.912	.722	.794	.850		
BI	.894	.680	.701	.824	.825	
CE	.925	.756	.803	.749	.775	.869

3.2 Structural model

Good model fit is a necessary condition for the use of structural equation modelling models, and the model fit related metrics in this study refer to the research recommendations of McDonald and Ho (2002)[12], Barlow (2006)[13], and the metrics used contain the chi-square identification of $\chi 2$, $\chi 2$ ratio of freedom, goodness-of-fit index (GFI), adjusted goodness-of-fit index (AGFI), comparative fit index (CFI), root mean square of the error of approximation (RMSEA), non-normed fit coefficients (NNFI), and comparative fit index (CFI).

Table 3 displays the different fits of the model, all of which meet the recommended values, indicating a good fit for subsequent analyses.

Table 3. Model Fit

	Recommended value	Index	
Bollen-Stine $\chi 2$	the smaller, the better	222.703	Matched
df	the smaller, the better	145	Matched
$\chi 2$/df	1 < $\chi 2$/df < 3	1.536	Matched
GFI	>0.9	.903	Matched
AGFI	>0.8	.859	Matched
RMSEA	<0.08	.066	Matched
TLI(NNFI)	>0.9	.957	Matched
CFI	>0.9	.963	Matched
IFI	>0.9	.964	Matched

Table 4 presents the validation of the research model's assumptions. Four assumptions were valid, and one was not. The results indicate that immersion (β=0.58, $p<0.01$) had a significant positive effect on perceived enjoyment. Perceived enjoyment had a significant positive effect on behavioral intention(β=0.723, $p<0.01$). Additionally, behavioral intention (β=0.417, $p<0.01$) and immersion (β=0.511, $p<0.01$) were found to have a significant effect on cognitive engagement. Although immersion did not have a significant effect on behavioral intention (β=0.127, $p>0.05$), H4 was rejected.

Table 4. Hypotheses analysis

DV	IV	Std	Unstd	S.E.	C.R.	P	SMC	Hypothesis
PE	IM	0.58	0.513	0.093	5.505	***	0.681	Support
BI	IM	0.127	0.116	0.114	1.024	0.306	0.685	Not Support
	PE	0.723	0.746	0.142	5.258	***		Support
CF	BI	0.417	0.51	0.12	4.231	***	0.734	Support
	IM	0.511	0.57	0.11	5.189	***		Support

*** P-Value < 0.001

4 Discussion

4.1 Virtual Reality Immersion Enhances Student Cognitive Engagement

Studies have shown that virtual reality systems can enhance learning outcomes and cognitive engagement. The high immersion brought by virtual reality can significantly increase students' concentration on surgical operations and cognitive engagement indicators. Virtual reality enables learners to manipulate a virtual environment through direct and indirect interaction functions, providing multi-channel perception, direct manipulation, and real-time response interaction modes[14]. This allows for a more natural learning process, activating additional sensory-motor brain regions and resulting in a more effective learning experience for intravenous injection with active participation and high levels of performance. Meanwhile, high cognitive engagement can significantly improve learners' ability to transfer knowledge and retain information[15].

4.2 Immersion in Virtual Reality Does Not Increase Student Learning Motivation

According to the data, immersion does not have a direct impact on learners' willingness to learn actively. In fact, some studies have shown a negative correlation between immersion and willingness to learn[16], as higher immersion can lead to higher external cognitive load, which can increase fatigue during the learning process. The mediating effect of perceived pleasure indicates that immersion can only indirectly influence willingness to learn behaviour through perceived enjoyment. Immersion has a greater mediating effect on willingness to act when perceived pleasure is high.

When using virtual reality for clinical nursing teaching, it is important to focus on the emotional experience of the learners rather than just immersion. The learners' motivation to learn is not directly related to their immersion in hands-on learning with the help of virtual reality. In fact, a high sense of immersion without a positive learning experience can lead to cognitive fatigue, which in turn reduces the learners' willingness to actively engage in learning. In addition, immersion has a certain degree of influence on learners' enjoyment. Learners with high immersion are more engaged in learning, but not necessarily motivated to learn actively. On the other hand, learners who experience pleasure are more motivated and engaged in learning.

When using virtual reality for teaching, the technology can enhance the learner's interest by providing novelty and creating a positive emotional experience. However, it is important to control cognitive fatigue caused by over-immersion of users. Virtual reality should be designed to enhance the emotional experience. In addition to visual information, it can also utilise 3D audio[17] and other technologies to simulate a realistic operating environment.

5 Conclusions

The study investigated the effectiveness of virtual reality intravenous teaching systems in enhancing students' clinical nursing skills. The results showed a positive correlation between the level of immersion in the virtual reality system and students' cognitive engagement in an educational setting. When utilising virtual reality for clinical teaching, experiential and affective elements of learning, such as immersion and perceived pleasure, can facilitate students' cognitive engagement in learning. However, immersion alone does not directly impact students' willingness to learn. It is important to note that this system is still in the developmental stage and some of its features are still being refined.

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