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Does the Virtual Environment Design influence Learning?

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Abstract

Past studies have shown that virtual reality (VR) is an advantageous medium to learn or train in various situations over traditional methods. Virtual environments are usually modeled and implemented to be representative of the training situations. However, in an objective to maximize the effectiveness and efficiency of VR for knowledge transfer, we may wonder whether the virtual environment itself really matters or not. In this paper, we propose to compare two different virtual environments implemented for the same training purpose. The scenario chosen relates to learning the right procedure to limit the spread of viruses. The two environments have been designed to be radically opposed: the first one is a dreamlike environment, while the second represents a medical laboratory. A user study was performed to compare the level of engagement and knowledge acquired by the participants in both environments. User experience, commitment, emotion and learning outcomes were measured. Results indicate no significant difference in the environment design on learning, feeling, commitment and sense of presence.

CCS Concepts

• ***Human-centered computing*** → ***Virtual reality;*** • ***Applied computing*** → ***Interactive learning environments;***

1. Introduction

Learning by doing is a recognized method for enhancing the memorization of gestures [AS79]. However, traditional mock-ups may not accurately represent real-life situations, limiting their effectiveness [JVJJ17]. The emergence of virtual reality (VR) provides a unique opportunity to immerse users in realistic environments.

This paper aims to study the influence of the virtual environment design on procedure learning within VR. By investigating different VR environments, we aim to enhance our understanding of how environmental factors impact knowledge transfer and learning outcomes. We consider here a simple use case related to sanitation.

1.1. Related work

In cognitive psychology, two knowledge transfer types are identified: vertical and horizontal [BCD89,RN96,BKBT08,PS92]. Vertical transfer involves using prior knowledge to construct new knowledge, and is common in procedural tasks with step-wise sequences. Vertical transfer shows high success rates for learning procedural tasks, but lacks adaptability to new situations. Conversely, horizontal transfer applies knowledge to solve new problems or tasks. It includes near and distant transfers. Near transfer resembles learning conditions, while distant transfer involves significant differences. Bossard et al. [BKBT08] also identified general and specific transfers. General transfer involves multiple domains, while specific transfer concerns a close or related domain. Depending on the learning goals and virtual reality scenarios, knowledge transfer and the application design differ.

Past research in the training field has demonstrated the interest of immersive technologies to facilitate learning and improve learning outcomes, thanks to their ability to involve users to move and interact in close-to-real situations [Car17, GGW*15], without endangering trainees or immobilizing physical systems. Especially, information retention is more effective in VR compared to traditional methods [AVM18,MGC*14,HHB*18]. Reasons put forward are an increase in user engagement [Car17, AVM18], a positive perceived experience [AVM18], virtual environments that can be close to reality [Car17,GGW*15], or the ability of immersive technologies to help people with poor spatial ability better understand [SWC19,MGKK*13,LW14]. However, to ensure effective learning applications in VR, certain conditions must be met. Presence in VR should be enhanced to mimic real-world behavior [Car17, Sla09]. The virtual environment design should align with the learning objective [BCD89, NCW*03], while interaction modalities should be relevant and not overwhelming [NCW*03, BKK*22]. Pre-training tutorials help users focus on the content rather than on the technology [NCW*03]. Furthermore, multi-sensory cues enhance immersion, engagement, and emotions [Car17].

To improve learning retention, tailored and evidence-based training is recommended, in some cases, realistic reproductions help understand and boost acceptance [NCW*03, BKK*22]. Varying session duration's further sustain attention [NCW*03, BKK*22], and the session structure should consider the topics and audience characteristics. Indeed, cultural sensitivity is crucial for the content design [NCW*03]. Producing positive emotions linked to the topic of the training is also an efficient way for a better remaining of

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the content [NCW*03, TASM17, Bow92, Pek14]. Lastly, measuring outcomes quantitatively and qualitatively helps identify areas for improvement [NCW*03, BKK*22].

Most virtual learning applications in the literature focus on vertical and specific transfer in industrial and educational contexts [Car17, GGW*15, MGC*14]. These applications create virtual environments (VE) that resemble real-life situations, with realistic places and object behaviors, enhancing users' sense of presence. However, designing virtual environments for horizontal transfer is not straightforward [HHB*18, BKK*22, BKBT08]. Given the vast possibilities of VR, replicating real environments exactly may not be necessary for optimal commitment, learning outcomes, and overall experience. This raises the question of the relevance of faithfully reproducing physical environments, considering the significant time and resources required, without necessarily benefiting learning outcomes. Fictitious or dreamlike environments, demanding fewer resources, can be valuable and non-interfering for knowledge transfer. Previous research has also explored learning during lucid dreams, demonstrating positive effects on learning, primarily in the context of sports training [HHF14, ES15, GBP*21, KDR19].

1.2. Contribution

Our contribution, therefore, is to get insights on the level of (un)realism it is possible to achieve to maintain at least, or improve, the effectiveness of knowledge and skill transfer in VR. The use case we consider here corresponds to horizontal knowledge transfer. We developed a virtual reality application following past recommendations [AVM18, MGC*14, HHB*18, Car17, GGW*15, Sla09, BCD89, NCW*03, BKK*22], in which users have to learn the right procedure to prevent viruses from spreading. This specific procedure will be applied in different everyday situations, hence we wonder whether the virtual learning environment has any effect on learning efficiency. We implemented two different virtual environment designs that are radically opposed: the first one being realistic according to the literature, and the second one being dreamlike.

2. Experimentation

2.1. Virtual training application

Two immersive applications were developed, each of them featuring the same training content but different VEs (Fig. 1). Both applications were developed in Unity3D, and run on Oculus Quest 2 headsets. The training scenario consisted in learning procedure to reduce the spread of viruses by air, such as the SARS-COV-2 or the flu, including washing hands and wearing face masks. The application design incorporated insights from past research, including the creation of a tutorial and step-by-step instructions for completing the training [NCW*03, BKK*22] (Fig. 2 left). To facilitate navigation within the virtual environments, a teleportation technique was implemented. This choice aimed to mitigate common issues associated with virtual navigation, preventing distractions and reducing cybersickness that could negatively impact immersion [KCC20]. Interaction with virtual objects in the environments was enabled through a self-activated virtual laser beam when user aims interactive objects. Given the virus prevention context, a feature was added to allow users to virtually contaminate the environment. This

Table 1: *Task instructions for participants*

Step	Instruction (Environment)
1	Find a flower and blow on it. (1) Describe the microscopes. (2)
2	Describe the controllers. (1 and 2)
3	Describe (the character) (the glass instruments).
4	Find the (fountain and wash your hands) (sink and wash your hands).
5	Take the face mask next to the (fountain and wear it) (sink and wear it).
6	Go back to see the (character) (lab equipment).

involved speaking or coughing into the embedded microphone, or touching virtual objects without using virtual protective equipment (Fig. 2 right). Participants accessed a menu to launch the tutorial, proceed to the training scenario, and consult task instructions. The participants had to explore the VE and fulfill all tasks of the list displayed on the menu to solve the challenge (Table 1).

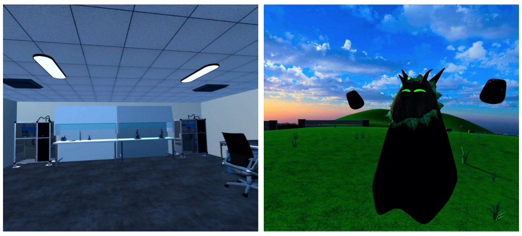

Figure 1: *Left: realistic laboratory environment. Right: dreamlike environment, here a grassland with an imaginary character.*

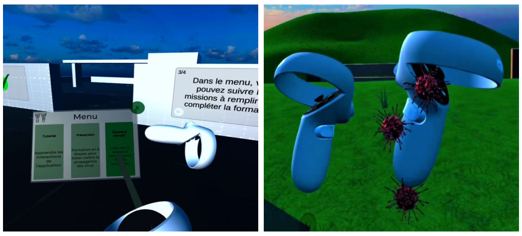

Figure 2: *Left: tutorial environment to learn the different interaction modalities with explanation spots. Right: viruses attached to the virtual controllers.*

The training environments were designed to be radically different to study their effect on learning, user feeling and commitment. The first design consists in reproducing a biomedical laboratory, close to real conditions where cleanness is of primary importance. To bring more realism to the virtual environment, an ambient sound of ventilation was added. Coughing without virtual face masks or touching objects without virtual protection gloves virtually contaminates them. A sink is present in one room to virtually wash hands. When hands are washed, the environment gets decontaminated.

The second design consists in a purely fictitious joyful dreamlike grassland with trees and flowers, as well as an imaginary character to enhance the sensation of joyfulness. Ambient sounds of birds and wind were added to increase immersion. Coughing without virtual face masks makes the flowers wither and kills the character. A fountain is present in the grassland to virtually wash hands. When hands are washed, the character becomes alive again.

2.2. Participants

A total of 19 participants ($M = 33.13 \pm 13.36$ years old, 7 females, 1 non-binary) were invited to participate voluntarily in the experiment. They were recruited within the university and from a private company nearby. The participants' age ranged from 22 to 60 years old. Only one participant had never used a virtual reality headset before the experiment.

The experiment included two groups:

- Group 1: using the application in a distant transfer situation (i.e., the environment is radically different from what the participant may encounter for the situation in which the skills learned must be used). This group corresponds to testing the application with the dreamlike environment (condition 1).
- Group 2: using the application in a near transfer situation (i.e., the environment is similar to what the participant may encounter for the situation in which the skills learned must be used). This group corresponds to testing the application with the realistic environment (condition 2).

Eight participants were in Group 1 and eleven in Group 2.

2.3. Experimental procedure

Upon arrival, participants were requested to fill a socio-demographic paper-based questionnaire, asking their background in VR, their emotional states [RWM89] but also three actions they think the most important to stop virus spread. Participants were then equipped with an Empatica E4 wristband. This device was used to measure the galvanic skin response (GSR) to assess their sense of presence in the virtual applications [RDI03, TM19], and their emotional state [MK08]. A baseline measure of the GSR was made by asking participants to stand still for 10 seconds. After wearing the head-mounted display, they started immersion with the tutorial, then they were transported in either learning environment.

Upon completion of the task in the environment assigned, a paper-based questionnaire was submitted to participants to report subjectively their emotional state after exposure, and the answers to the same questions concerning the three actions they think the most important to stop contamination. Additional questionnaires were administered for presence [WS98] to ensure that participants are immersed, commitment [PTK12] and cybersickness [BMP05]. No time limit was imposed on participants to complete the questionnaires, which took between 5 and 10 minutes. The average time needed to complete the tutorial was 4 minutes, and 5 minutes for the training session.

2.4. Hypotheses

Based on past research, we made the following hypotheses:

H1 The learning outcomes are at least equally effective in both VEs.
H2 The training application has an effect on learners in both conditions:

- Learners gain knowledge
- The commitment to learn is high
- The experience is perceived as positive
- The sense of presence is high

Table 2: *Word cloud statistics before and after exposure to VR.*

	Condition 1		Condition 2	
	Before	After	Before	After
Number of different terms	11.0	9.0	8.0	5.0
Word diversity / participant	1.4	1.1	1.1	0.6
% of participants who answered "washing hands"	18.2	64.0	0.0	85.7
% of participants who answered "wearing mask"	36.4	64.0	57.1	85.7

3. Results

3.1. Data analysis

To analyze all data, normality checks were first conducted with Shapiro-Wilk tests. Since all data were found not to follow a normal law, a non-parametric test was applied for each measurement, with a significance level of .05.

3.2. Recall effect of the VR application

Participants were asked prior and after exposure to list in an open format the three most important actions to avoid contamination. Results, presented in Table 2, show an increase of the number of occurrences for the terms "washing hands" and "wearing mask", or similar terms, after the VR exposure. The "Number of different terms" in this table refers to the total number of different terms written by participants in each group. In order to compare the groups, we calculated the word diversity ratio per participant by dividing the number of different terms by the number of participants.

3.3. Presence and commitment

Participants were asked to rate their presence and commitment on a 7-point Likert scale from -3 (do not agree) to 3 (fully agree). The questions, based on [WS98, PTK12], were as follows:

Q1 The application was complicated to use
Q2 I always knew what to do in the application
Q3 Did the environment react to the actions you initiated or carried out?
Q4 Did the experiences in the virtual environment seem consistent with your experiences in the real world?
Q5 To what extent were you involved in the experience of the virtual environment?
Q6 Did the manipulation and interaction devices interfere with the execution of the requested tasks?
Q7 Did you feel so involved in the task that you lost track of time?

Q1 to Q6 refer to presence while Q7 relates to commitment. For each question, Mann-Whitney tests did not manifest significant differences between both conditions (Table 3).

Additionally, the galvanic skin response (GSR) was measured (in μS at a 4Hz frequency) throughout the experiment. For each period of the experimentation (tutorial, then training), an average value of the GSR was computed. However, due to hardware issues, measures were not exploitable for one participant in Condition 1 and 6 participants in Condition 2. The analysis on 7

Table 3: *Statistical values for each question.*

Question	Mean (SD)		U	p-value
	Condition 1	Condition 2		
1	-1.37 (1.51)	-1.45 (1.91)	48.00	.77
2	-0.20 (1.98)	0.81 (1.83)	29.00	.21
3	1.62 (1.99)	2.45 (0.52)	34.50	.48
4	2.12 (0.83)	2.09 (0.83)	44.00	.88
5	2.37 (0.51)	2.45 (0.68)	39.00	.79
6	0.00 (1.51)	-0.91 (2.25)	55.50	.35
7	1.85 (0.90)	1.63 (1.80)	35.50	.79

participants in Condition 1 and 5 participants in Condition 2 revealed an increase of the GSR in each condition between the tutorial and the training sessions: for condition 1, a Wilcoxon signed-Rank test revealed a significant increase ($M = 139.12\% \pm 146.99$, $Z = 2.09, p = .015$, while for condition 2, no significant increase was found ($M = 68.17\% \pm 59.31$), $Z = 1.64, p = .062$. Furthermore, a Mann-Whitney test revealed no significant difference between both conditions, $U = 24, p = .34$.

3.4. Cybersickness and emotional state

Participants had to rate their cybersickness level using the Misery Scale [BMP05], on a 11-point Likert scale (0 = no problem and 10 = vomiting). A Mann-Whitney test did not reveal any significant difference between conditions, $M_{C1} = 0.14 \pm 0.37, M_{C2} = 0.54 \pm 0.75, U = 26, p = .34$.

Participants were requested to report their emotional state prior and after exposure on an emotion grid [RWM89], consisting in a two-dimensional grid, with the horizontal axis displaying the level of pleasure and the vertical axis measuring the level of arousal. The results are broken down for each axis. The center of the grid corresponds to a neutral level, while the extremes range from -4 to 4. To measure the effect of training, for each participant, the evolution between pre and post-exposure along the two axes was calculated. A Mann-Whitney test on the horizontal axis revealed no significant difference between both conditions, $U = 36.5, p = .98$. Similarly, a Mann-Whitney test on the vertical axis revealed no significant difference between both conditions, $U = 37, p = .94$.

4. Discussion

We made the hypothesis that the learning outcomes would be at least equally effective in both conditions, regarding the answers of the question about the three actions to prevent from virus spread. Results show no significant differences between both environments in terms of presence, commitment and emotional state. Furthermore, we can observe through the word clouds that the objective of the training is met in both environments (which is obtained the terms “washing hands” and “wear a mask” after exposure). This is in line with past findings about the relevance of VR for learning [BKBT08, BCD89, Car17]. Though, the results presented here have limitations in establishing a causal relationship between the virtual environment design and learning efficiency. Further studies with larger sample sizes of participants and varied methodologies (e.g., different learning procedures, more various VEs in terms of plausibility) are needed to ascertain the true effects of the virtual environment design on learning efficiency.

On the other hand, we observed immediate effects of the training applications on participants, whatever the environment design, with a high level of presence — grades are clearly above 0 for Q3-5 (positive feedback) and below 0 for Q6 (positive feedback) on a $[-3;3]$ scale –, an average score for commitment of 1.74 on a $[-3;3]$ scale, and the experience being perceived as positive with an average increase of pleasure of 0.812 on a $[-4;4]$ scale, and an average increase of arousal of 0.825 on the same scale, which confirms our second hypothesis. These results are also in line with past studies listing the conditions for a learning application to be effective [AVM18, BMP05, BKBT08, Bow92, BCD89, HHB*18, HHF14, KCC20, KDR19, LW14]. On an objective side, the GSR revealed an increase from the tutorial to the training session in both conditions, however this increase was significant only in the first condition. This increase may be due to an emotional arousal related to the immersion in an environment that may not be expected by participants for such task [RWM89, Sla09, SWC19].

As limitations, the topic of the training was familiar to the participants, due to the past COVID-19 pandemic. This may explain the high percentage of good answers after the training. However, it is interesting to note that many participants did not give the right answers prior to exposure, and that they had to be immersed in the virtual environments to recall them. Another limitation of our study is that we only measured short-term memory. To complete the study, the same questions concerning the actions to limit the spread of viruses should be asked after a longer time, for example a week or a month. Furthermore, complementary measures could be set up to better characterize the learners’ state during training. Additionally, we extracted questions from the Witmer and Singer presence questionnaire to ensure participants were immersed in both VEs without overloading them after exposure, however, presence might not be assessed accurately with only a subset of questions. Other means of presence measurement will be considered, including integrating questionnaires in the VEs [SKHH19].

5. Conclusion

In this work, we evaluated whether the VE design had an effect on learning in a non-procedural scenario. Our results did not manifest any significant impact of the virtual environment design on learning efficiency. However, in both cases, a recall effect is present, and emotions arouse from the virtual experience. Our first results tend to reveal that the learning subject is of primary importance, thus it has to be considered in the design of a VR application. Numerous past works show that a replication of the environment is crucial for a procedural task, such as a mechanical assembly. Whereas in our study, for tasks, such as non-procedural ones, that can be adapted to various situations, the VE itself seems not critical. In our particular scenario, this observation may arise from an a-priori knowledge of the learning subject due to past experience. Therefore, in future works, we will consider scenarios in which we may be sure that participants will not have prior knowledge to validate our assessments.

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