An evaluation on the effectiveness of virtual tutorials for training emergency professionals*

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Abstract

The use of virtual reality as a tool for professional training enables access to knowledge in a more active way. Applying it in high-risk situations training encourages finding the most effective way to share knowledge. With this objective in mind, video game tutorials as a method of learning in virtual environments are becoming increasingly popular. This study proposes a methodology in which virtual reality tutoring techniques are applied to enhance learning in training for radiation emergencies. A virtual reality experience involving a high-risk situation has been developed. In this experience two groups of professionals involved in such emergencies participated, one group were trained with a tutorial, and the other group faced the simulation without it. The results show that participants who received tutoring were able to solve the test correctly in a more effective way.

Keywords

Virtual reality, virtual environment, learning process, detection, video game, emergency, human computer interaction, military

1. Introduction

Radiation emergencies are high-risk and stressful situations in which an accident involving radioactive material has occurred. They differ from nuclear emergencies in that radiation emergencies occur outside nuclear power plants. For example, accidental exposure to stolen radiation sources or accident during transport of radioactive materials. Given the presence of radiation, it is important for professionals in this sector to be prepared to act without errors that could negatively affect health. Therefore, training must be conducted to enable professionals to acquire knowledge and skills necessaries to address these situations. However, these simulations have a high economic and organizational cost. This lowers the frequency of conducting drills, which could negatively impact the efficiency of the professionals' learning process. Furthermore,

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using radioactive elements in real simulations is extremely dangerous. Therefore, an alternative to these elements is to indicate the radiation levels of the environment with piece of papers. This kind of partial solution limits the effectiveness of the exercise because radiation detector devices are not used, not even virtually. Drills also cannot replicate dangerous situations with precision. For instance, an earthquake causing a nuclear power plant explosion and its radiation cloud approaching the population. These differences from the real world prevent trainees from having full immersion, which limits the successful performance of the exercise. Therefore, many studies and programs have started using different technologies to ensure effective and safe training.

Virtual reality is becoming increasingly accessible to the public. This technology is primarily used in the entertainment industry but can also be employed for learning and training purposes. One of the greatest challenges of this technology is user adaptation. Virtual reality aims to recreate the real world and all the interactions that can take place within it. To achieve this, individuals need a process of adaptation to use this technology naturally. VR developers offer tutorials covering these initial concepts to assist in the adaptation process. However, these tutorials are often quite generic and subject to change based on the video game or application specifications. Therefore, the development of a specific tutorial phase is necessary. Through the tutorial, it is expected that the user will be able to use the application successfully. In this way, the user will adapt to the technology, and an improvement in the final exercise results is expected.

Tutorial design is original from the video game industry. Each day, these entertainment systems become more complex. Users often need a learning process to fully enjoy the experience. Consequently, nowadays, almost all commercial video games feature a tutorial to meet these needs. As a result, extensive research has been conducted on tutorial design and implementation. The goal is to create a satisfying experience with a non-intrusive learning process so that users can learn while being entertained.

In this work, a virtual reality tool has been developed for training professionals in radiation emergencies. In this experience there are a main scenario and two preliminary tutorial phases. In these tutorial phases, the user will learn how to interact with their environment and the objectives they must be met for a successful execution of the exercise. An experiment session was conducted to test the effectiveness of the learning provided by this tool. 6 sector professionals were evaluated. These professionals were divided into two groups. One group were trained beforehand with the tutorial, while the other team received no training. The analysis was conducted by observing the total duration, interactions with elements, completed objectives, and movement efficiency. The *trained group* achieved better results in all the analysed variables. While the sample size is limited by the number of available professionals, the results indicate that the benefits of the tutorial phase are clear. Nonetheless, the developed application and applied tutoring techniques demonstrate a notable improvement in user performance.

2. Previous work

Professionals facing risky situations must undergo prior training. Effective learning poses many challenges when preparing a training simulation. Therefore, since 2010, research in virtual reality for conducting these processes has seen significant growth, as noted by Radhakrishnan et al. [1]. Radhakrishnan emphasizes that the use of virtual reality can be effective in training for skills in the industrial sector. Military forces have been using this technology for their training for many years [2]. Progress can also be found in the mining sector [3], healthcare [4], and even in emergency situations [5, 6]. This is made possible by advances in this technology. This evolution has allowed users to experience a sufficiently high level of immersion to conduct a training session successfully [7], which also entails a disturbance in the physiological state of participants, similar to what is achieved in real training scenarios [8].

However, humans are still not used to this technology. This often leads to adaptation problems. Usability issues can result in improper training [9] or even worse outcomes compared to traditional methods [10]. Adapting to this technology is a widespread issue. Companies like Meta [1] and Steam [2] are working to improve the usability of their products with initial tutorials. However, these tutorials are generic and subject to modification based on the specific needs of the application being used. This leads commercial video games like Skyrim VR (Bethesda Softworks, 2017), Beat Saber (Beat Games, 2019), or Windlands 2 (Psytec Games Ltd, 2018) to create their own tutorials. This problem is also observed in the field of science. Various research projects involving virtual reality have developed generic tutorials [11] or specific ones to teach users how to interact with the environment [12, 13, 14]. Adaptation is not the only issue that necessitates the application of tutorial techniques. The complexity of video games is also significant [15]. Considering the complexity of responding to risky situations, the implementation of such tutorials is considered necessary.

Tutorials can be presented to the user in different ways. Frommel et al. [16] emphasize that this information should be context-sensitive, meaning that the tutorial should be an integral part of the experience. The information provided should be related to the current task to maintain immersion. Green et al. [17] propose the existence of three types of tutorials based on (1) instructions that guide the user step by step, (2) examples that demonstrate consequences, and (3) carefully designed experiences that allow the user complete freedom to practice.

It is important to understand how information is presented to the user. Kao et al. [18] mention that the most tutorials present information in a textual format. This format yields poorer results but is the most common across all applications. The Multimedia Learning Theory of Mayer [19] provides a list of 12 principles that can be used to enhance learning in desktop applications. Some of the most important principles include the *coherence principle*, which states that all irrelevant material should be avoided, the *personalization principle*, where information should be presented using informal narrative, and the *signaling principle*, which emphasizes the importance of highlighting important materials.

Tutorials can also incorporate cues to guide the user's next steps. In this regard, notifications in the head-up display are the most effective, although they can be intrusive, they are always detected by the user. This is crucial if you want the user to perform specific actions. Another way to prevent the user from getting lost is by using visual cues [20]. These cues can help users identify which objects to interact with or where they need to go.

Virtual reality is a powerful tool for professional staff training. However, usability and the

[1]Meta First Steps: https://www.meta.com/es-es/experiences/1863547050392688/, accessed on 26/9/2023.
[2]SteamVR: https://store.steampowered.com/app/250820/SteamVR/?l=english, accessed on 26/9/2023.

complexity of concepts require the application of certain techniques to enhance learning. These techniques can be derived from tutorials, the majority of which originate from the world of video games.

3. Design and development of a virtual reality training tool

As previously mentioned, a virtual reality application has been developed for training professionals in emergency situations. Within this tool, a tutorial has been implemented with the aim of enhancing the learning process. It is expected an improvement in the final performance. The results are based on the analysis of user behavior, which is examined through the analysis of predefined set of objectives and interactions.

3.1. Objectives, interactions and movement

There is a wide variety of potential scenarios classified as radiation emergencies. For this study, it has been decided to recreate an emergency where a car accident has occurred. A van was transporting radioactive material for industrial radiography. The accident has occurred within a city. In this scenario, there is an element emitting low levels of radiation, an injured person, and a witness. Additionally, there are traffic cones to stop traffic and radiation detectors to measure the environment radiation. The exercise consists of some objectives that the professional should accomplish. The objectives aim to list the basic actions that an involved personnel must carry out based on the operating protocols. The professional should gather information about the incident, secure the area, address the problem while considering the radiation of the environment, and report what has happened. These tasks were the following:

The specific objectives were gathering information from characters, protecting and talking to the injured person, cutting off traffic, inspecting the van, checking the radiation levels, informing the head office and return home.

Most of these objectives have a natural completion order, and the user must follow it. However, depending on the situation, the user may consider another order is more suitable. For instance, it was important to ask witnesses about what happened, but it was not necessary to do so in this precise order. In order to complete all the proposed objectives, the user must be able to interact with elements in the environment. The interactions were aiming or stop aiming, interacting with an object, using correctly or incorrectly an object, picking up or dropping an object, positioning correctly or incorrectly, talking to a character and moving.

The virtual environment takes place outdoors and covers extensive area. The user needs to move freely in order to complete the objectives. Therefore, it has been decided to give freedom of movement to the participant [21]. However, due to the virtual environment size and the fact that head-mounted display is wired, the user cannot get to certain places. As a result, it has been decided to allow the user to teleport as well [22]. Teleportation is the action that the user performs when moving in virtual reality. This teleportation moves the user instantly to the participant's place of choice. To perform teleportation, the user must press and hold a button on the controller, which will display a laser-like beam. The user will teleport to the location aimed at with the laser when the button is released. These objectives, interactions, and movement have been the events used to analyse the user's performance.

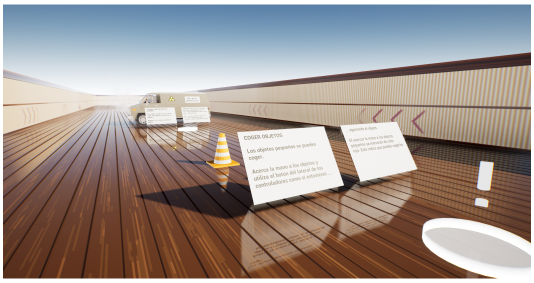

Figure 1: Tutorial sandbox scenario

Figure 2: Assessment scenario

3.2. Scenario and interactive tutorials to learn how to act

The virtual reality application consists of three scenarios: the *tutorial sandbox scenario* for learning interaction, the *guided emergency scenario* to understand the objectives, and *assessment scenario* in which the effectiveness of the solution if checked.

Tutorial sandbox scenario is created for users to learn to interact with the elements of the environment (see Figure 1). To achieve this, they will be presented with a linear scenario. To prevent user disorientation, directional cues have been placed on the walls of the environment, indicating the direction to follow [20]. The tutorial explain how to teleport for movement; pick up and drop small items; interact with large objects; talk to characters; measure radiation; inform to the head office about the situation, and finish the exercise. These explanations are presented in the form of text within floating panels in the scenario. Right next to each explanation are the elements with which the user should interact for practice.

The user must face the described emergency on *guided emergency scenario.* This phase teaches the user the steps they need to take to respond to an emergency successfully. The application will guide the user with the objectives they must fulfill at each moment. These objectives are ordered, and the user is obligated to follow the instructions. The user is informed about the current task through a panel that appears on the head-up display. This panel appears when a new task needs to be performed. This way of notifying the user is intrusive but effective [23]. In this way, the user always has the information about what to do.

Finally, *assessment scenario* is a phase where the user must put their knowledge into practice (see Figure 2). In this scenario, the same emergency as in *guided emergency* phase has happened. The difference between these phases is that *assessment* takes place in a different location; the position and distribution of elements are different, and the user is not guided. In this unguided phase, the user is free to fulfil the objectives they deem appropriate and in the order they choose. The data obtained from this unguided phase will be used for the final analysis.

4. Experimental setup

The impact of experimenting the tutorial phase was analysed through a practical experiment. An HTC Vive Pro 2 virtual reality wired headset was used for this purpose. To do this, participants were divided into two groups. The first group, called the *untrained group*, only completed the *assessment* scenario. On the other hand, the second group, the *trained group*, went through all the

Table 1
Mean duration of *assessment* phase by groups. Duration is measured in seconds

	Duration (s)	
	M	SD
Untrained	809	150.63
Trained	346.33	96.83

scenarios. This way, the *trained group* learned to interact with the elements in the environment, to move, and to understand the objectives they had to achieve. However, participants in the *untrained group* had to discover all of this on their own.

Participants were informed about the study's goal and were told that they could end their participation at any time. Then, participants were briefed about the virtual setup and informed about the possibility of a simulated radiation leak. Controller buttons were explained to the participants before starting the experience. After this, participants were introduced to the virtual experience. The *trained group* began with the *tutorial sandbox* scenario and then moved on to the *guided emergency*. There was no time limit in both of these scenarios. Once they completed these two phases of the experience, the user was introduced to the *assessment* scenario. For this phase, participants had a maximum of 15 minutes. The *untrained group* only experienced the *assessment* scenario. The maximum duration was the same.

At the end of the experiment, users filled out a questionnaire about personal data and information regarding their skill and previous experience with virtual reality. Additionally, in this questionnaire, they were asked to express their personal opinion about the experience. This information will be used to improve the tool for future applications and experiments.

5. Results

A total of 6 adult professionals participated, all of whom were male members of the Spanish Military Emergency Unit. 50% of them had never used virtual reality before, but 100% had previously participated in real radiation emergency simulations. Participants B, D, and F had never used virtual reality. Participants C and E had used it only once. Participant A had used this technology a few times. Participants were divided into two groups, 3 users for each one.

This quantitative analysis aimed to identify the behaviour differences between trained and *untrained group* achieve this, the data collected from the *assessment* phase was compared. All the results indicate a positive learning and adaptation process for the *trained group*.

5.1. Differences in duration

The average duration (see Table 1) for the *trained group* has been 346.33 seconds, while the *untrained group* took an average of 809 seconds. The standard deviation of the duration for the *untrained group* has been lower.

Table 2
Duration of *assessment* phase by user. Duration is measured in seconds. The highest line indicates the maximum time, 15 minutes.

	Untrained			Trained		
	UserA	UserB	UserC	UserD	UserE	UserF
Duration (s)	883	945	599	214	382	443

Table 3
Average and standard deviation of interactions, completed objectives, and teleportation events performed by the user

	Completed objectives		Interactions		Teleportations	
	M	SD	M	SD	M	SD
Untrained	5.67	0.47	632	156.44	233.33	52.82
Trained	8.33	0.47	209	103.71	133	30.63

Table 4
Number of interactions, completed objectives and teleportation events performed by each user

	Untrained			Trained		
	UserA	UserB	UserC	UserD	UserE	UserF
Completed objectives	6	5	6	8	9	8
Interactions	581	844	471	137	356	135
Teleportations	198	194	308	95	170	134

5.2. Differences in the number of performed actions

Participants in the *trained group* tend to fulfill more objectives while performing fewer interactions and movements (see Table 4). The average number of objectives completed (see Table 3) for the trained and untrained teams are 8.33 and 5.67, respectively. In both cases, the standard deviation is below 8%. The *trained group* has been closer to achieving the 9 objectives. The *trained group* takes an average of 41.58 seconds to complete an objective, while the *untrained group* takes 142.68 seconds.

The average number of interactions with the elements conducted by the *trained group* is 209, and for the untrained team, it is 632 (see Table 3). In both cases, the standard deviations are quite high, especially for the *trained group*. User E has interacted with the elements more than twice as many times as their peers D and F. These groups have achieved a ratio of 25.09 interactions per task for the *trained group* and 111.46 interactions per task for the *untrained group*.

The *trained group* has used teleportation more frequently (see Table 5). On average, teleportation has been performed 233.33 times for the *untrained group* and 133 times for the *trained group*. Unlike the untrained users, trained users have attempted to teleport directly to locations where

Table 5
Movement distance by each user in the virtual world through teleportation and distance walked in the real world. Both are measured in meters

	Untrained			Trained		
	UserA	UserB	UserC	UserD	UserE	UserF
Virtual Reality	323,75	387,1	593,1	188,96	362,87	270,45
Real world	234,89	195,37	258,05	82,36	136,35	145,07

Table 6
Movement distance mean and standard deviation by group in virtual world and real world. Both are measured in meters.

	Virtual Reality		Real world	
	M	SD	M	SD
Untrained	404.32	147.62	229.43	25.88
Trained	274.09	30.63	121.26	27.74

the objectives are located (see Figure 3). Additionally, the teleportation distance in the virtual environment and the distance the user has moved in the real experimental environment have also been calculated. The sum of the teleport distance for the *trained group* has been lower, both in the virtual environment and the real world (see Table 6). For each objective, the *untrained group* has made 41.15 teleports and covered a total distance of 111.77 meters. On the other hand, for each objective, the *trained group* has made 15.97 teleports and covered a total distance of 47.46 meters.

6. Analysis and discussion

As shown in Table 1, the difference in durations is clear. The *untrained group* tended to use all the available time. The minimum duration of the *untrained group* is higher than the maximum duration of the *trained group* (see Table 2).

An analysis of the fulfilled objectives shows that the trained team is more efficient in achieving almost all the objectives in a shorter time compared to the untrained team. Considering that the experience comprises a total of 9 objectives, it can be said that the trained team has performed well in resolving the exercise. None of the users in the untrained team gathered information by speaking with the witness or informed to the head office. In the case of the trained team, participant D did not stop traffic, and participant F also did not speak with the witness. It seems that participants consider that seek external sources of information regarding the incident is not important.

In the case of performed interactions, the average number for the trained team is 66.8% lower. Furthermore, this group has managed to complete almost all objectives with a lower number of interactions. However, it is important to note that in several instances, users unintentionally repeated interactions. This is because there are small objects, and the system is highly sensitive.

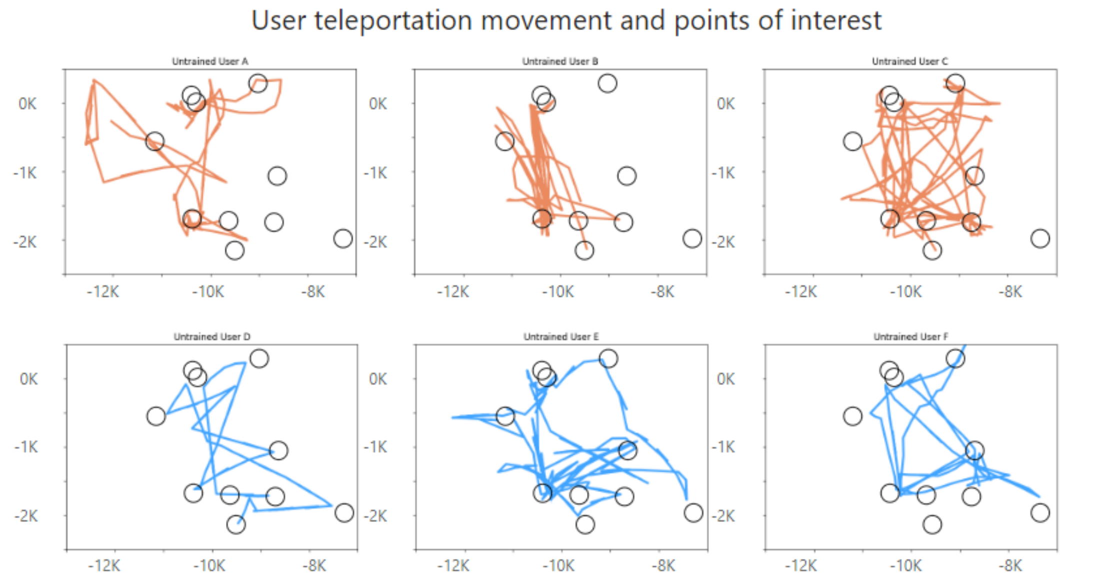

Figure 3: User teleportation movement. Top row is for untrained users and bottom is for trained. Circles mark the objectives places.

Therefore, the system detects that the user has performed actions numerous times, such as pointing at a specific object they want to interact with. Interactions performed on the same object within the same second are considered system errors and have been excluded. However, a more reliable study is needed to identify which interactions can be considered noise. Users B and E are the ones who have performed the most interactions in each group (see Table 4). This has led to an increase in the average for each group and in the standard deviation. In this variable, it can also be observed that the user who interacted the least in the *untrained group* did so more times than the user who interacted the most in the *trained group*

The *trained group* performs a more efficient movement. This group has achieved lower results in number of teleportations and lower movement distance, both in the virtual and real-world scenarios. This shows that this group needed to travel less to successfully resolve the emergency. Furthermore, observing Figure 3, it can be seen that trained participants take a more direct route between points of interest in the environment.

The furthest users are B and E. B is the one who has completed the fewest objectives, while E has completed the most. Analyzing user B, it can be observed that they have had the most number of interactions. However, in terms of movement, they have moved the least. This shows that most of this group participants was focused on achieving nearby objectives, and they did not move to find new objectives. On the other hand, participant E is the one who has had the most number of interactions and has moved the most in order to fulfill all objectives. Unlike participants in the same group, this behaviour has led the participant to successfully complete the exercise.

7. Conclusions and future work

Virtual reality enables professionals to undergo effective training for health-threatening situations. The presented research has developed a virtual reality application for this purpose. To assess the effectiveness of the tool, an experiment was conducted with professionals involved in these emergency situations. In the experiment, a group of participants was trained with a tutorial stage, and another group did not receive any training. The results demonstrate that the group receiving the tutorial performed better in the assessment stage. The sample size is relatively limited, but the participants in the experiment are professionals involved in radiation emergencies.

This work focuses on the learning process in emergency situations. To complete the study, several extensions and further research will be considered in future work. First, it is necessary to observe the persistence of learning over time. To do this, the same professionals will be asked to participate in future experiments, allowing for an analysis of their memory and learning. Second, there are numerous possible radiation emergencies. Therefore, studies will be conducted with other scenarios. This variety of scenarios will allow for the study of user behavior regardless of the specific situation. Finally, these situations are dangerous and increase the stress levels of professionals. The physiological state of the participants may be related to their behavior and the learning process during simulations. Stress should be analysed and taken into account. One way to detect the stress and anxiety of participants is by using biometric sensors [24]. The enumerated studies will enable the comprehensive development and analysis of a tool that will aid in training professionals for radiation emergencies.

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