Training nurses in VR: exploring spatial mapping and free-hand interaction
Formation des infirmières en RV : exploration de la représentation spatiale et de l'interaction par suivi des mains

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ABSTRACT

Virtual Reality can provide an immersive training environment in nursing education, in particular to experience situations that cannot be perceived in the reality. Through a user-centered design process with educators and students from a nursing school, we developed a VR application for asepsis training in a blood sampling scenario. The simulation allows to visualize the contamination risks during the procedures. We conducted three tests and continuously improved the application in order to increase the usability and the feeling of immersion. During the tests, we compared two interaction modalities, two visualizations of the hands and different degrees of immersion (teleportation, or mapping a real simulation room, with the possibility to walk and touch physical elements). These experiments allowed us to draw a conclusion on the level of immersion reached by the new virtual reality technologies and on their possible implication in the practical training of students.

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IHM '23, April 03–06, 2023, TROYES, France

ACM ISBN 978-1-4503-9824-4/23/04.
https://doi.org/10.1145/3583961.3583980

RÉSUMÉ

La réalité virtuelle offre un environnement de formation immersif dans l'enseignement des soins infirmiers, en particulier pour expérimenter des situations ne pouvant être perçues dans la réalité. Par un processus de conception centré sur l'humain avec des éducateurs.trices et des étudiant.es d'une école d'infirmières, nous avons développé une application de RV de formation à l'asepsie lors d'un prélèvement sanguin. La simulation permet de visualiser les risques de contamination lors de la procédure. Nous avons réalisé trois tests et amélioré continuellement l'application afin d'augmenter la facilité d'utilisation et le sentiment d'immersion. Nous avons comparé deux modalités d'interaction, deux visualisations des mains et différents degrés d'immersion (téléportation ou marche dans une représentation réelle d'une salle pour toucher les objets physiques). Ces expériences ont permis de tirer une conclusion sur le niveau d'immersion atteint par les nouvelles technologies de RV et sur leur implication possible dans la formation pratique des étudiant.es.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**; *Virtual reality*; • **Applied computing** → Interactive learning environments.

KEYWORDS

Virtual Reality, asepsis, simulation, contamination, Oculus Quest, training

MOTS CLÉS

Réalité virtuelle, asepsie, simulation, contamination, Oculus Quest, formation

ACM Reference Format:
Marine Capallera, Leonardo Angelini, Alexandre Favre, François Magnin, Mariateresa de Vito Woods, Omar Abou Khaled, and Elena Mugellini. 2023. Training nurses in VR: exploring spatial mapping and free-hand interaction. In *IHM '23: Proceedings of the 34th Conference on l'Interaction Humain-Machine (IHM '23), April 03–06, 2023, TROYES, France.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3583961.3583980

1 INTRODUCTION

Medical errors are the third leading cause of death in the United States with 250,000 deaths per year after heart disease and cancer [13]. An article in Becker's Hospital Review [21] lists the nine most common medical errors in the United States, including surgical site infections (SSI). According to the article introducing the Safe Surgery Trainer project [11], communication failures are responsible for approximately 70% of deaths due to medical errors. This figure is taken from the 2006 Patient Safety Goals of the American organization The Joint Commission [5]. In the document "Global Guidelines for the Prevention of Surgical Site Infection" [18] the World Health Organization proposes a list of 29 recommendations made by 20 of the leading experts in the field. In particular, chapter 3.3 of the document deals with the importance of a clean operating room environment and the decontamination of medical devices and surgical instruments.

Infection control is therefore a key element in the training of nurses and several practical simulation activities are carried out during student training. In this regard, most nursery schools have simulation rooms in order to replicate a typical hospital care environment where students can train with the real-word instruments, medical mannequins and simulated patients. Access to the simulation rooms is obviously restricted because of its high occupancy and is typically regulated by an academic calendar. New technologies, and in particular virtual reality, could bring a concrete benefit to training practices, because they allow not only to optimize the use of the simulation rooms (thanks to a reduced time for the installation of the required equipment) but also to make completely abstraction of it, allowing the student to train directly at home and/or outside of academic hours. Indeed, the diffusion of Virtual Reality (VR) headsets at an affordable price opens new perspectives in practical training in nursing. In particular, in this article we refer to the Oculus (now Meta) Quest 2 headset, available on the market at a price of 450€ (at the time of writing), which allows experiencing high-fidelity virtual environments without the need for a dedicated machine for graphic rendering.

The main goal of this work is to set up a simulation environment for asepsis through an iterative design in collaboration with health teachers and students. This application aims to allow the simulation of blood sampling with visualization of contamination in a learning context. The research question is therefore to compare and evaluate, thanks to this approach, the modalities of interaction which will then be used in the context of the learning of future nurses. These should allow for a feeling of immersion and acceptability for the future use of this learning device.

In this paper, we present the iterative process carried out to develop an application providing a pertinent training and an acceptable user experience. Its purpose is to understand its relevance and usability for a future hybrid learning pathway, supported by digital tools in addition to the the current simulations in the real environment. In particular, during this process, we explored different interaction modalities (controllers and hand gestures) and different levels of virtuality (teleportation in completely virtual environment or spatial mapping of a real-room, with the possibility to touch physical elements) for increasing the usability and the feeling of immersion for nursing students (usually not acquainted with VR technologies).

The article is structured as follows: Section 2 presents previous work in the field of serious games for contamination awareness and virtual reality in nursing education. Section 3 presents the state of the art of VR platforms and of the interaction techniques (controllers or hands-free, teleportation or walking in the physical room) explored in our study. Section 4 presents the iterative, user-centered design and development methodology. Section 5 presents the developed nursing scenario, the contamination visualization system as well as the score system implemented to gamify the training. Sections 6 and 7 present the methodology and test results for the first two versions of the application. Finally in Section 8 we discuss the results and present future research directions.

2 RELATED WORK

The objective of this chapter is to identify the state of the art of serious games in the field of health, then to study the use of VR in this field as well as its limitations.

2.1 Serious game

In addition to the playful aspect, serious games fulfill an educational objective, while keeping the possibility to train independently. These applications are therefore well suited to the fields of training and health [20]. 3D Virtual Operating Room [19] is a 3D serious game allowing to train health professionals to the challenges of the operating room, from the reception of the patient to his exit from the operating room. In this multiplayer game, the user has the possibility to play different roles in the operating room. The principle of the game is based on observation, communication between the different players and decision making. The objective is to demonstrate the impact of communication failures on decision making. At the end of a scenario, participants can see the mistakes they made and have access to the solutions. Finally, the players participate in a collective debriefing.

Safe Surgery Trainer [11] is a 3D serious game for training perioperative staff (preoperative, intraoperative and postoperative) working in the operating room. The user has the possibility to play different roles in the operating room. The game also focuses primarily on communication in the room. The player progresses through the different scenarios by making decisions among the choices offered while answering theoretical questions. The game also provides feedback to help the player improve. It contains a "Tutorial" mode where feedback is given directly after the player has made a decision and another mode that lets the scenario continue and then presents the feedback to the player at the end of the game.

I.Control [8] is a 2D serious game fighting mainly against nosocomial infections [1] by raising awareness of health professionals but also individuals to the prevention of infections in the medical field (hand hygiene, respiratory hygiene, blood exposure, ...). The game is a series of real cases for which the user must choose the right precaution to adopt. The user has the choice between playing as a doctor or a patient. There is no real score, the objective of the game being to win all the rewards (passports and trophies). A training mode is also available to practice some of the topics in Standard Precautions. These include hand hygiene, clothing, respiratory hygiene and risks of exposure to biological products.

CatCare [10] is a serious in Augmented Reality. The objective is to raise awareness of hand hygiene in stressful situations among healthcare workers. The principle of the game is to feed and water sick cats. There are two beds with 5 cats in each one. The sick cats in the first bed have a different disease than the cats in the second bed and the latter must remain in quarantine. When a user touches a sick cat, the disease settles on the virtual hand and in order not to transmit this disease to a cat affected by the other disease, the user will have to wash the infected virtual hand with the tap. An interesting aspect of the game is the way the diseases are visualized. Indeed, the user can identify the disease of a cat thanks to the colored particles that gravitate around it. These particles are also visible on the virtual hand when it is infected. The difficulty does not increase over time but there are 4 different levels of difficulty. In the last level, the particles representing the disease are no longer visible.

Although these previous serious games already implemented techniques for sensitizing to the risk of infections, they weren't developed as immersive VR simulations, which can improve the learning experience [24]. We were inspired by CatCare for the representation of the contamination and for the creation of two levels: the basic level, with contamination visible during the interaction, and a more difficult level, with the possibility to see the contaminated objects only at the end of the game.

2.2 Virtual reality in healthcare context

There is a wide range of applications for VR in the healthcare field. Some of the uses identified by Moline [16] include telepresence for operations, simulation of procedures before surgery, therapies (e.g., agoraphobia), prevention and patient education, education and training (e.g., visualization of anatomy, laparoscopy). According to Moline, VR would bring certain benefits such as cost reduction (e.g. telepresence) or performance improvement (e.g. paroscopy simulator). VR would also save non-renewable resources (e.g., cadavers, animals, ...).

[1]Infection contracted as a result of or during a stay in a health care facility

Seymour et al. [27] have shown that VR simulations improve dexterity and performance in the operating room while reducing the error rate. A group trained with VR and another without VR training were evaluated during laparoscopic cholecystectomy [2]. Although the psychomotor skills of the subjects were equivalent, the study counted 6 times more errors and 5 times more chance of injuring the gallbladder or burning non-targeted tissue on the side of the group without VR training. In the conclusion, the article even mentions the idea of evaluating and certifying health professionals with such tools.

Nevertheless, several limitations now exist for the use of VR in concrete applications. According to Moline's [16], VR in the field of health would include a number of limitations such as the sense of smell and touch. The absence of these senses results in a decrease in the realism of interactions. For example, although palpitation is widely used in reality, it is a priori non-existent in current applications. Motion sickness is also a serious concern. According to an experiment cited in the article, 89 out of 146 healthy people tested suffered from nausea after only 20 minutes of use. There is also a trade-off between the level of realism and the quality of interactions due to the limited computing power of the systems. For telepresence, for example, latency is also an obstacle.

Rayan et al. [24] conducted a systematic review systematic on the use of VR in medical learning.However, very few studies use VR headsets. A first study used one quest in clinical observation [3], another used a Rift in the domain of neuranatomy [30]. Finally, one study used a htc vive for anatomy education [7]. Rourke [23] analyzed 9 studies in order to compare the effect of virtual reality simulation and real-world simulated practice in the acquisition of clinical psychomotor skills for pre-registration nursing students. The author analyzes in particular measurement of knowledge acquired during the studies, skill performances, skill success and time to complete skill. However, studies use different virtual reality devices (visualization through a monitor or a headset) as well as the presence or not of haptic feedback. Overall, the systematic reviews show that virtual reality appears to be an effective method for developing these types of skills.

Shorey et al. [28] conducted a systematic review on the use of VR among nursing students and registered nurses. Their analysis includes eighteen studies and focuses on the impact of VR on learning outcomes: skills-based, cognitive, and affective. They highlights the use of both desktop virtual simulation (in majority) and immersive virtual simulation. They concluded that virtual environments may be used to teach theoretical knowledge in nursing education.

It is worth noting that just two studies using immersive virtual reality for teaching nurses were found by Rourke [23] in 2020 but they did not use a VR headset. Just five studies were found by Shorey et al. [28] in 2021 and non of them use a VR headset as mentioned, showing that this field is still underdeveloped.

To summarize we found only three study in literature that used immersive virtual reality for educational purposes in healthcare. Two of them where used for learning anatomy, and another for clinical observation practice. To the best of our knowledge, so far no study analysed the benefits or the feasibility of an immersive VR application using a VR headset for asepsis training.

[2]Removal of the gallbladder by making incisions in the abdominal wall

2.3 Mixed Reality in Meta Quest

During our iterative design of the VR application for asepsis training we investigated if the use of mixed reality, i.e., adding elements of the real world in the virtual world could increase the student's feeling of being immersed in the simulated hospital environment. The first element to be investigated are hands. In May 2020, Oculus released an SDK update that made it possible to track the user's hands through the integrated cameras. Thanks to this update, it is possible to make the user interact with object in the virtual world without the need for controllers. In the past, hand-free interaction in VR environment was typically enabled through additional head-mounted cameras or sensors (e.g., Leap Motion [25]), requiring a careful calibration with the VR environment. The work of Masurovsky et al. [14] confirms the importance of hand tracking, especially when the use of both hands is necessary. The work of Khundam et al. [9] seems closer to ours, but the kind of gestures to be performed in their app are quite different from ours (e.g., fine manipulation of the needle). Moreover, we think that for VR training in the care domains, it is important to evaluate presence and not only usability. Voigt-Antons et al. [32] evaluated the impact of hand tracking over controllers with the Oculus Quest for the tasks of grabbing and typing, showing that hand-tracking led to higher valence, but lower arousal and dominance (SAM questionnaire [4]). The lower dominance, as discussed by authors can be due to a lower feeling of precision/control compared to controllers. Grabbing was also reported to be more realistic, and participants experienced a higher presence (IPQ questionnaire [26]). These results are interesting but could differ in our interaction context, where participants should grab and turn objects in 3D and have a different background (nursery). Voigt-Antons et al.[32] also showed that participants, when interacting with controllers, preferred to see a representation of both the hands and controllers in the virtual environment.

Considering our application, participants would need to move around the room in order to perform a blood sampling. Typically, in virtual reality users can teleport using the controllers. A teleportation gesture is not available, in hand-tracking mode, among the predefined gestures of the Oculus SDK. A gesture for teleportation is available in the Microsoft's Mixed Reality ToolKit [6] but this would require using all the interactions available in the toolkit. We had therefore to develop in our app a teleportation gesture similar to the one available in MRKT. An alternative to allow people move inside the room is to enable real walking in a room that is identical to the simulation room where students typically train. Indeed, replicating in VR the same size of the room it would be possible to make the students walk freely in the room and even touching walls and pieces of furniture. Spatial Augmented Reality is a common approach for merging real and virtual worlds [17], but was typically developed through projection mapping, which can be expensive and require calibration. Roo and Hachet [22] recently explored the possibility to map physical elements to a virtual world experienced through a Virtual reality headset (HTC Vive). Simeone et al. [29], introducing the idea of Substitutional Reality, explored the possibility to map a real room to different virtual environments, suggesting that since in VR it would be difficult to replicate the look of the materials of real objects, participants would rather prefer objects that looks quite different from the reality, while still being able to feel their presence in VR. Also Simeone et al. they used a tethered headset (Oculus Rift DK1). To the best of our knowldege, no paper reported about mapping physical elements in the Oculus Quest. However, a YouTuber recently showed how to replicat his house in the Oculus Quest [31]. Inspired by these possibilities and by previous work, we wanted to understand the impact of introducing elements from the real world on the degree of immersion, the user experience and the usability of a training application for nurses. Increasing the realism of the simulation is important to ensure the students ability to transfer theirs skills to the real world such. Indeed, in the learning of emergency gestures and care, simulation, simulation and repetition are essential methods in applied pedagogy in this field. [1].

3 ITERATIVE DESIGN OF THE VR APPLICATION FOR NURSE TRAINING - FIRST VERSION

The serious virtual reality game presented in this article was developed with an iterative process over a year and a half starting in September 2019. Despite the difficulties related to the COVID-19 pandemic, we followed a user-centered approach, firstly, with the follow-up of health professionals throughout the project, secondly, with user tests conducted at three different phases of the project. The first version of the application prototype was developed with the Oculus Quest (first version) and tested in April 2020 with 4 HEdS professors. This first version implemented a basic blood sampling scenario. Users could interact with the controllers and move around the scene with the teleportation technique. For this first version, users noticed a lack of realism, especially for the interactions to be performed when drawing blood. Due to the initial difficulty in interacting with the controllers and the different gestures compared to a real scenario, the teachers made several contamination errors, being focused on the interaction rather than on the task to perform. The feeling of immersion and realism was therefore broken for these users. In response to this initial feedback, we decided to improve our application in several ways

(1) Definition of scenarios and 3D models that are more faithful to the typical gestures and tools of daily nursing practice. To do this, we analyzed an illustrative video of blood sampling, used in the training process of nursing students. We have recreated with Blender software or purchased all the 3D models necessary to faithfully recreate the blood sampling scenario. The different steps to follow for a blood test were integrated in the application in order to verify the correct execution, especially with regard to the gestures necessary to avoid contamination.
(2) Exploration of the hands-free interaction, thanks to the new hand tracking algorithm provided by Oculus.
(3) Exploration of the possibility to map a real room in order to move by walking and interact with physical elements.

4 VR APPLICATION FOR NURSE TRAINING - SECOND VERSION

Starting from the perspective for improvement identified from the test of the first version of the app, in the second version we

explored different different mixed reality scenarios for improving the application. It is important to note that the Oculus Quest does not allow to track objects and that in our applications we will be able to interact only with virtual objects, except for fixed objects in the room: with a good calibration we will be able to interact with a piece of furniture, for example pressing on a real cabinet to open a drawer of the corresponding virtual cabinet.
As for the first version, the application has the goal to promote the autonomous learning of the students and the development of professional health skills. Thus the exercise was designed to replicate as far as possible the simulation done indoors with a mannequin. This didactic allows:

- repetition of the procedure to promote the learning phases: cognitive, associative and automation [1]
- to receive feedback at the end of the simulation on the validation criteria and on the time (from the web interface)
- to work between students and create a challenge between them: best time (minimum time to complete all steps), best score (correct execution of the steps).

More specifically, the indicators of success are hand disinfection at the right five times, the safety of the caregiver (wearing gloves) according to standard precautions, the chronology of carrying out a blood test.
We recreated a care room that replicates the one in the HEdS simulation center 1. The degree of fidelity is very high (to the centimeter) in order to improve the feeling of immersion and to allow a direct mapping of the room. In this way, we were able to test a modality of interaction in mixed reality [15], in order to be able to touch real objects when moving in the room and interacting with the virtual environment. Several 3D models were also set up for the medical accessories (tourniquets, Vacutainer® tubes, swabs, needles...) as well as for the furniture (cart with trash and disinfectant, glove box...) and for the patient (visible vein, bleeding simulation...). The following scenario has been agreed with the professors of the University of Health and implemented in an Oculus Quest application with the Unity software:

(1) Hand disinfection
(2) Placement of tourniquet,
(3) Localization and disinfection of the puncture area,
(4) Respect of the 30" time of action of the disinfection,
(5) Wearing of protective gloves
(6) Removal of the needle protection
(7) Inserting the needle of the sampling device
(8) Inserting the Vacutainer® tube into the sampling device
(9) Collection of blood
(10) Removing the Vacutainer® tube
(11) Removing the tourniquet
(12) Remove the needle of the sampling device and activate the "anti-stick" protection on the needle
(13) Apply a compress to the puncture area
(14) Dispose of the puncture material in a "safeBox"
(15) Apply a dressing to the puncture area
(16) Removal and disposal of gloves
(17) Disinfection of hands.

For each correct step (checked in Unity with collision models), the system assigns points. Additional points are assigned according to the speed of execution of the scenario, in order to introduce a further element of competition between the students. However, speed of execution has a lower weight on the final score than compliance with asepsis. The points obtained as well as the ranking of each student can be visualized in a web application, accessible to students and teachers. The application also gives feedback on the performance in relation to each of the criteria (described above) with particular mention of the errors made during the care scenario.
A particularly important feature of the proposed application is the possibility to visualize the contaminations as colored dots. There are purple if the source is the patient: for example when the nurse touches the patient with gloves and then forgets to throw them away. Whereas they are yellow if the source is the nurse: for example when s/he forgets to disinfect her/his hands after entering the room. As for the CatCare game [10], two levels of difficulty of visualization are available: in the easy mode, the nurse can see the contaminations during the execution of the scenario, in the difficult mode s/he can see them only at the end. In this case, s/he will be able to see, for example, that after forgetting to disinfect her/his hands, s/he has contaminated the cupboard he opened to retrieve the Vacutainer®.

5 EXPERIMENT 1: PRELIMINARY TEST OF THE SECOND VERSION

5.1 Method

In the preliminary test of the second version of the application we conducted three experiments, each of which aimed to compare different immersion conditions:

(1) Input mode (I): hand tracking (I_H) VS joysticks (controllers) (I_C)
(2) Visualization (V) of the hands in the (I_H) condition: "Hands only" (V_H) VS "Hands and controllers" (V_HC) (the "controllers only" condition was discarded as less immersive, as shown in previous studies [32])
(3) Room Mapping (M): Full Mapping (M_C) VS Partial Mapping (M_P). In the first case, it is a matter of completely mapping the room in order to allow the student to fetch an object from a real wardrobe; in the second case, it is a matter of mapping only the bed and the cart and making all objects available in the cart, without the need to walk in the room. This second configuration would be useful in order to allow the simulation in another room that does not have the same configuration as the one mapped in the application

The test took place at the HEdS, in a room identical to the one mapped in the application 2. Nine users (six women) participated in this test. Seven of them are nursing students, two are computer science students. Eight users were between 20 and 24 years old and the last one was 52 years old. Participants reported being fairly comfortable with new technology (3.33 / 5.00) but not very familiar with VR and hand tracking in VR (1.56 / 5.00).
Each user tested three factors (I, V and M) each comprising two conditions. The experiment was divided into three phases. For example, for phase I, they had to complete part of the 17 steps for both conditions. For phase V it was about manipulating different objects while for phase M they just had to explore both conditions

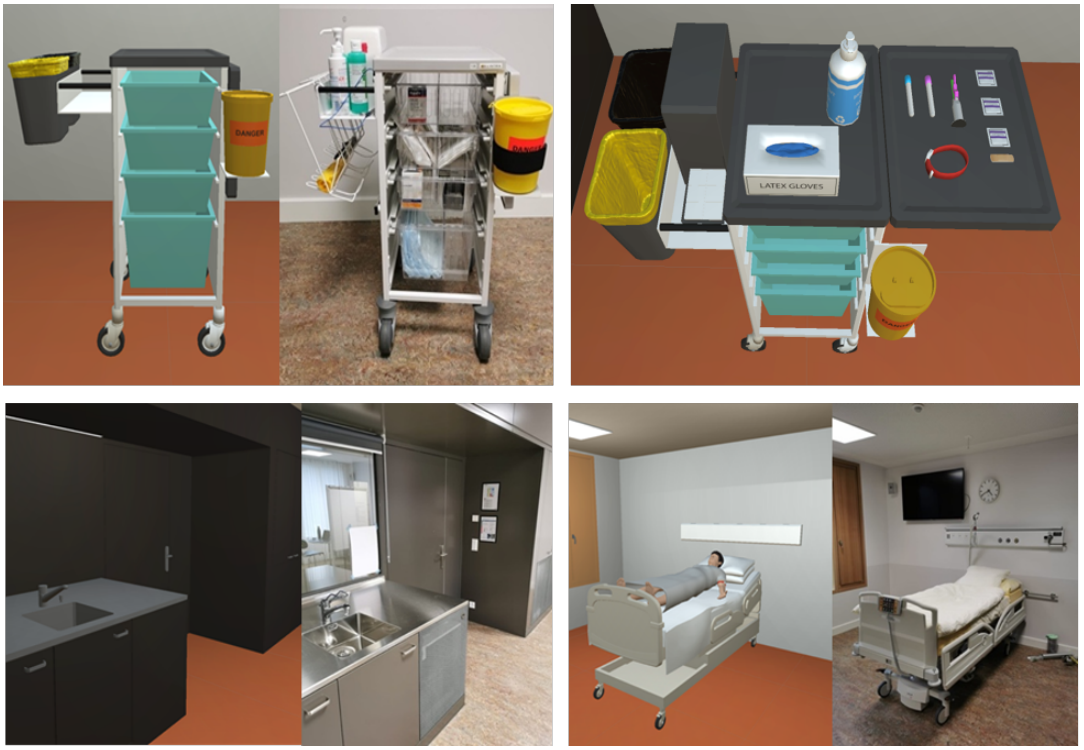

Figure 1: Virtual environment (left in each image) and real environment (right in each image): cart, bed, tap and cabinet

for a few minutes each. At the end of each phase, they completed the evaluation questionnaires. All participants were separated into two equivalent groups assigned to a different sequence: (V_H, V_C, I_H, I_C, M_C, M_P) and (M_P, M_C, I_C, I_H, V_C, V_H) for minimize the order effect. The test duration was approximately 30 minutes. The order of the experiments and conditions was crossed to avoid learning effects.

For each of the three experiments we asked the Self-Assessment Manikin (SAM) questionnaire [4] (1 to 9 scale, using intermediate scores between each pictogram), which aims at determining the emotional feeling of the users in terms of activation (A), valence (V) and dominance (D), and the Igroup Presence Questionnaire (IPQ) [26] (-3 to +3 scale), which measures the feeling of immersion according to the axes of spatial presence (SP), involvement (INV) and perceived realism (REAL). For the input modality experiment (I), which replicated most of the scenario described in section 5, we also asked the System Usability Scale (SUS) questionnaire [12]. Since the other two modalities (V and M) were shorter, we retained this unnecessary questionnaire.

5.2 Analysis

Given the small number of participants, the data collected had a non-normal distribution. We therefore compared the two conditions of each experiment with a Wilcoxon signed-rank test. We therefore report the median of the results instead of the mean.

5.3 Results

The following table reports the results (median) of the questionnaires for each experiment Table 1.

The analysis of the results of the experiment on the input modality (I) shows us that there are no significant differences in terms of feelings, immersion and usability between the two conditions tested (with hand tracking (I_H) or with the Oculus controllers (I_C)). Indeed, if on the one hand the use of the hands to interact would seem at first sight more natural and immersive compared to the controllers, on the other hand, the user is forced to keep a sometimes unnatural position with his hands, in order to ensure a good tracking by the helmet. The pinching gesture to grasp a virtual object is quite natural, but the hand tracking part can often break the immersion. This can happen if the hands are occluded, or simply touching, if the user turns his head and keeps his hands in front of him, or simply during movement, if the headset has trouble tracking the hands. The tracking of the controllers is much more accurate, without the risk of occlusion, and easily allows the user to ignore the tool with less risk of breaking the immersion by unnatural behaviors of the virtual hands. Of course, for some people learning to use the controllers may be a barrier, as we noticed with a user who was older than the others. In this case, hands-free interaction is much preferable. For the rest of the project, we decided to keep the two interaction modalities: "you just have to put down the joysticks to switch to the hands-free modality". We note that the SUS score for both modalities approaches 85 points, which is considered "excellent" [2].

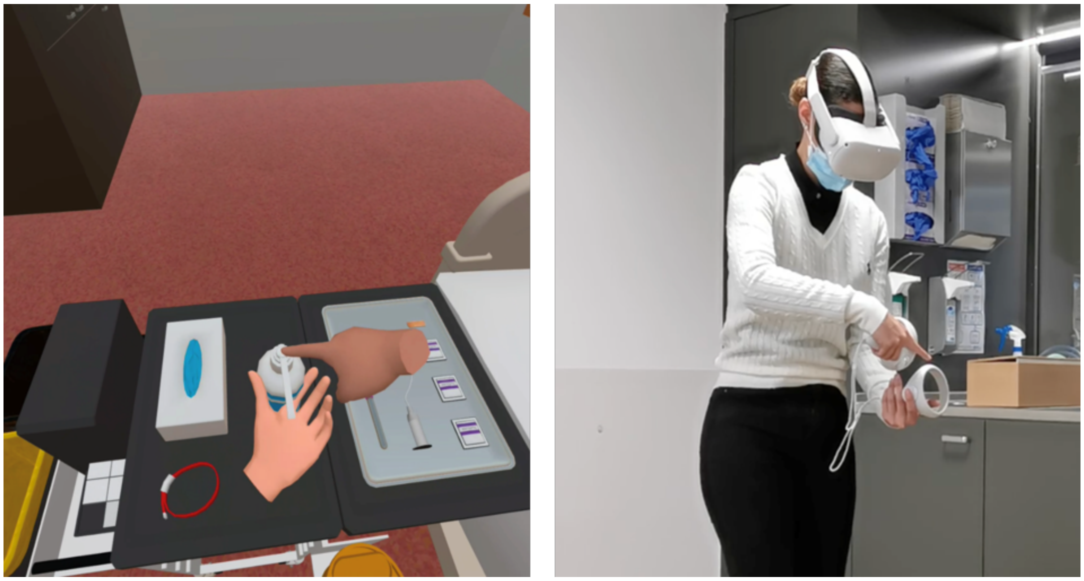

Figure 2: User test: hand sanitization scene. Virtual scene on left and real scene on right

Table 1: Questionnaire results (median) for the pre-tests. Significant results in *bold italic*

		SAM	IPQ	SUS
Input modality (I)	***Hands (I_H)***	V: 8.00	SP: 2.20	SUS: 82.50
		A: 8.00	INV: 1.25	
		D: 7.00	REAL: 0.75	
	Controllers (I_C)	V: 7.00	SP: 2.40	SUS: 85.00
		A: 7.00	INV: 1.25	
		D: 8.00	REAL: 0.75	
Visualization (V)	***Hands (V_H)***	V: 7.00	SP: 2.60	
		A: 7.00	INV: 1.00	
		D: 7.00	REAL: 0.25	
	Hands and Controllers (V_HC)	V: 7.00	SP: 2.00	
		A: 6.00	INV: 1.00	
		D: 6.00	REAL: 0.50	
Mapping (M)	***Partial (M_P)***	***V: 7.00***	SP: 2.00	
		A: 7.00	INV: 0.75	
		D: 6.00	***REAL: 0.25***	
	Complete (M_C)	***V: 8.00***	SP: 2.00	
		A: 8.00	INV: 1.25	
		D: 6.00	***REAL: 0.50***	

The second condition (V), like the first one, did not show significant differences between the different visualizations of the hands in the joystick interaction modality (E_C). Indeed, if the visualization of the hands alone (V_M) could be more immersive, for novice users the possibility to see the joysticks and the positioning of the buttons can simplify the interaction. As for the previous experiment, we decided to keep both visualization modalities.

The mapping condition (M) led to significant differences between the two conditions. Users particularly appreciated the possibility of walking freely in the room (M_C), which generated greater emotional activation (A) (Z=10.5, p=0.006) and more positive emotions (V) (Z=16, p=0.02). The perceived realism in the scenario with full mapping also benefited compared to the partial mapping (Z=2, p=0.04 with the Wilcoxon greater test.

For the next step, we decided to abandon the idea of mapping only the bed and the cart. Moreover, during the test we noticed that calibration losses of the room could occur. In case the surface of the virtual cart is lower than the surface of the real cart, the user might find it impossible to retrieve the virtual objects placed on its surface, because the real surface of the cart will physically prevent the passage of his hands or joysticks. This can affect both the full and partial mapping condition. In order to avoid this type of risk, we decided for the rest of the project not to map the cart and the bed (which should therefore not be in the physical zone of interaction), but only the external walls and the cabinets. Finally, in order to allow the use of the application in case the user is in a different room from the one mapped, in the final version of the application we have reintroduced the possibility to move in the virtual room by teleportation. As the teleportation gesture is not available in the Oculus Quest hands-free interaction, we have also developed a new gesture to teleport.

6 EXPERIMENT 2: FINAL TESTS

6.1 Methods

During the preliminary tests of our first application (Section 4), we saw that the lack of realism and the mismatch between the virtual simulation and the real world simulation constituted a barrier for the adoption of our training application. After the iterative improvements, we wanted to assess whether the final version of the application, which implements all the steps of the scenario described in section 5, would be significantly better than the first prototype. We conducted an experiment with 8 students (7 females) from the nursery university, aged between 20 and 23 years. In this experiment we compared three conditions: the previous prototype from the first experiment (A), the new prototype (B) with teleportation (B_T) as described at the end of Section 7 and the new prototype with the room mapping and real walking (B_W). In order to avoid a learning effect, half of the participants started with the old prototype, then with the new one with teleportation and finally with the real walk. The second half of the participants first tested the new prototype with real walking, then with teleportation and finally the old prototype. As input modality, we kept only the possibility of using the controllers for this test (I_C). We also gave the users the possibility to choose between viewing only the hands (V_H) or both hands and controllers (V_HC). The average time to complete a scenario independently of the real walking or teleportation condition was 530 s (+/- 80). At the end of the scenario we showed the score obtained on the web platform described in Section 5. We asked the same questionnaires as in the first experiment (I) of the previous test. We also asked open-ended questions to the participants regarding the score system and the simulated learning modality in VR, in order to understand the relevance of our application for their learning path.

6.2 Results

The same analyses of the previous test were conducted for this test. The results are reported in the following table 2:

We noticed that the realism perceived in the full mapping modality is higher than the one perceived in the teleportation modality, which shows the interest of the virtual reality to improve the feeling of immersion ($Z=1.5$, $p=0.02$). In both cases, the SUS shows an excellent usability of the application, in coherence with the preliminary test. Concerning the possibility to choose between the visualization of the hands only or the joysticks and the hands, 7 users preferred the first modality (V_H). All of them indicated that they were comfortable with the idea of making their scores visible to classmates and teachers and were very motivated by the ranking system. Finally, students confirmed that the prototype could really help them become more aware of hand hygiene while learning/testing their knowledge of the blood draw procedure. However, some participants noted that real training is still needed to learn the techniques.

In order to verify the benefits of the new version of the application, we compared this application with the first version of the prototype (see Section 4). We noticed, as expected, significant improvements in valence (V), activation (A), perceived realism (REAL) and usability (SUS). For the sake of brevity, the complete results of this test are not reported in this article.

7 DISCUSSION

The iterative design method applied during this research allowed to develop knowledge about the blood sampling protocol and more specifically about the asepsis and to accurately integrate such information into a realistic virtual reality experience for training nurses. Statistical analysis of the results showed that the new prototype provides a more positive, stimulating and realistic experience through a more usable system and that real walking leads to a more realistic experience than teleportation. The addition of this condition was not only to compare two different locomotion techniques. The main goal was to increase presence by creating a mixed reality environment, with virtual elements matching the position of real elements and by being able to touch the real elements present in the room (e.g., pieces of furniture). The comparison has implications for the deployment of our tool, which could benefit from the physical room to increase presence (real walking), or conversely, be used even at home or in non-equipped rooms to increase the accessibility of the tool to more students (teleportation). It was also found that there is a high probability that the new prototype provides a stronger sense of control than the previous one, thanks to a virtual simulation that is closer to their practice in real life. The SUS scores obtained for the new prototype were excellent (81.56 for teleportation and 84.69 for real-world walking), especially since the participants indicated that they had little or no experience with VR applications. Finally, students confirmed that the prototype could really help them become aware of hand hygiene while learning/testing their knowledge of the blood testing procedure. However, the realization of this application also showed the limitations of mixed reality with Meta Quest 2. In fact, it was decided to remove these physical objects from the middle of the scene (bed and cart) since an initial wrong calibration or a decalibration over time could cause major interaction problems, such as the impossibility to interact with virtual elements and bumping into real objects.

In our tests we could not found a significant difference between and hand tracking and the use of the controllers on usability (SUS) and presence. However, users seemed to strongly suggest through their performance and comments that hand tracking requires more training than controllers, which confirms Voigt-Antons et al. [32] findings. Users had to understand how to do the pinch gesture correctly and had to become familiar with the limitations of hand tracking (occlusion and limited tracking field). Meta recently released a newer version of the tracking algorithm, which should limit problems due to occlusion. Unfortunately, at the time of writing, we had not tested yet the newer version of the hand tracking and it is not possible to estimate the impact on the user experience

Table 2: Questionnaires' results of final test - significant results are in *bold italic*

	SAM ([1:9])	IPQ ([-3:3])	SUS
A medians	V: 6.50 A: 5.00 D: 6.00	SP: 1.40 INV: 1.13 REAL: -1.25	SUS (mean): 74.38 SUS (median): 76.25
B_T medians	V: 7.50	SP: 2.00	SUS (mean): 81.56
	A: 6.50	INV: 1.25	SUS (median): 82.50
	D: 7.50	REAL: 0.63	
B_W median	V: 9.00 A: 7.50 D: 8.00	SP: 2.00 INV: 1.00 REAL: 0.88	SUS (mean): 84.69 SUS (median): 83.75
Wilcoxon signed-rank test Z, p-value	A vs. B_T V: 0, 0.06 ***A: 1.5, 0.04*** ***D: 0, 0.039*** A vs. B_W V: 2, 0.05 ***A: 0, 0.01*** D: 1.5, 0.14 B_T vs. B_W V: 6, 0.40 A: 0, 0.17 D:7, 1.00	A vs. B_T SP: 4, 0.42 INV: 5.5, 0.68 **REAL: 0.8, 0.02** A vs. B_W SP: 8.5, 0.40 INV: 19, 0.45 ***REAL: 2.5, 0.01*** B_T vs. B_W SP: 9.5, 0.50 INV: 20.5, 0.31 **REAL: 1.5, 0.02**	A vs. B_T SUS: 2, 0.05 A vs. B_W ***SUS: 0, 0.04*** B_T vs. B_W SUS: 8, 0.35

and usability of our application. Concerning the impact of the immersion on the learning process, the literature [24] suggests that the immersive simulation should improve the learning experience. However, the benefits on the learning outcomes remains to be assessed. In general, learning outcomes obtained through immersive technology are comparable to those based on traditional learning methods [24]. If these findings would be confirmed also for our tools in a future pilot test, this would ensure that students could benefit of additional practical training in VR, without the need to access to the completely equipped simulation room.

8 CONCLUSION

In this article we have presented a virtual reality application that allows to simulate with a high degree of immersion a blood sampling scenario, with the possibility to visualize contamination due to errors in hand disinfection and hygiene. For us it was important to ensure that users are able to transfer the contamination effect of gestures in VR to real life consequences. Our first tests show that the application is easy to use and that students would be motivated by the associated gamification platform. The study conducted with the Oculus Quest 2 virtual reality headset shows that this tool could be a valid complement to the practice in the simulation center, to be used in simulation rooms outside of class hours or even at home. We have also shown that the spatial mapping of a real room into the virtual environment increases the perceived level of realism, although mapping objects in the room (such as the cart and the bed) should be avoided as it can introduce problems in case of decalibration. Finally, we have seen an advantage of using controllers instead of hand-tracking, as participants were able to learn fast how to use them and benefited from the higher precision.To the best of our knowledge, this is the first study that investigated the feasibility a VR headset application for asepsis training. The insights about the user preferences and usability of our system, show that such technology is a promising for developing new teaching tools for nursing education.

To continue this project, in order to validate the benefits on the learning of asepsis recommendations, we will provide a group of students with headsets with this application and we will compare their learning of good asepsis practices with a group that will not have access to this application.

Moreover, in the future, other scenarios could be implemented in addition to the blood test. Indeed, the platform is easily extensible and we have already used it to develop a scenario to raise awareness of hygiene measures in supermarkets to fight against the COVID-19 pandemic.

ACKNOWLEDGEMENTS

The authors would like to thank all the persons who contributed to this paper.

9 SUPPLEMENTARY MATERIAL

The video provided illustrates the complete course of the blood sampling scenario in "real walk" and "hands only" conditions (https://youtu.be/ZjGTkeMFcQQ). The left part of the video is the real world while the right part is the headset casting.

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