MIXED REALITY IN MEDICAL SIMULATION: A COMPREHENSIVE DESIGN METHODOLOGY

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ABSTRACT

In the medical education field, the use of highly sophisticated simulators and extended reality (XR) simulations allow training complex procedures and acquiring new knowledge and attitudes. XR is considered useful for the enhancement of healthcare education; however, several issues need further research.
The main aim of this study is to define a comprehensive method to design and optimize every kind of simulator and simulation, integrating all the relevant elements concerning the scenario design and prototype development.
A complete framework for the design of any kind of advanced clinical simulation is proposed and it has been applied to realize a mixed reality (MR) prototype for the simulation of the rachicentesis. The purpose of the MR application is to immerse the trainee in a more realistic environment and to put him/her under pressure during the simulation, as in real practice.
The application was tested with two different devices: the headset Vox Gear Plus for smartphone and the Microsoft Hololens. Eighteen students of the 6th year of Medicine and Surgery Course were enrolled in the study. Results show the comparison of user experience related to the two different devices and simulation performance using the Hololens.

Keywords: Design methodology, Training, Education, Medical Simulation, Mixed Reality

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1 INTRODUCTION

Medical errors and healthcare-related adverse events are proved in the 8% to 12% of hospitalizations, and 50% to 70.2% of such harm can be prevented through comprehensive systematic approaches to patient safety (WHO, European data, 2017). Adequate medical education must be highlighted as one of the most useful key drivers of quality improvement. For this reason, in recent years, the simulation-based learning model is replacing the traditional 'apprentice' learning model. Indeed, technological innovations, such as models, physical medical simulators, and extended reality (XR) simulations, have led to consistent improvement in learning outcomes. Students can learn better and retain information more effectively by engaging themselves in an immersive experience. Today's highly sophisticated simulators allow examining rare conditions and complex procedures and acquiring new knowledge and attitudes. The implementation of simulations and multidisciplinary scenarios of XR, based on real clinical practices, permits the training of medical and nursing students and the further education and training of healthcare professionals.

Augmented reality (AR) is considered useful for the enhancement of healthcare education because it increases the learning speed and makes the learning process easier (Zhu, et al., 2014). Moreover, other several benefits, of XR simulators' use in healthcare education, have been elicited in different studies: decreased amount of practice needed and errors, reduced simulation time and failure rate, improved performance accuracy, shortened learning curve, increased motivation and attention, improved trainees assessment, enhanced learning retention and performance on cognitive-psychomotor tasks, decreased cognitive load (Zhu, et al., 2014; Munzer, et al., 2019; Gerup, et al., 2020).

Therefore, AR allows for more authentic learning, making the simulations more realistic and immersive, and providing students a more personalized and explorative learning experience. It is considered useful also in achieving core competencies, such as decision making and teamwork.

Although the great number of positive aspects, the XR applications are not as widely accepted as they perhaps should be (Herron, 2016; Garzón, et al., 2017). The main reasons are the technical and usability issues, the time needed to train students on how to use XR applications, teacher resistance, and pedagogical issues.

Even if the design of medical simulations passes through a careful analysis of learning objectives, technology to be used, facilitator's role, and performance assessment, there is a series of issues that need further research, such as the integration of learning theories and strategies into the simulation design, the investigation of the educational context, learner types, and learning objectives (Gerup, et al., 2020).

In this context, the main objective of this study is to define a new integrative method to design and optimize every kind of simulator and simulation, to improve trainees' learning and performance.

2 EXTENDED REALITY IN MEDICAL EDUCATION

Simulation-based learning is an innovative teaching method that provides healthcare students and professionals with more opportunities to acquire knowledge, skills, and attitudes for developing clinical abilities (AL Sabei, et al., 2016). By presenting the trainee with a variety of procedures, exposure to a specialty will be more consistent and uniform and learning can occur more rapidly, without the necessity of waiting for a patient with a specific disease (Dawson, et al., 1998). Simulation can be classified into human or non-human simulation: in the first case it is carried out as a role-play among students, in the other case it is accomplished using a manikin or computer. It may be also classified according to the type (compiler-driven and event-driven) or the fidelity (low, medium, and high-fidelity) (Elshama, 2020). A medical simulator is purpose-designed as a system or device with interactive features that actively engage students in a real-world clinical process. It mimics human patients and allows recreating specific clinical interactions such as clinician(s)-patient. The great level of realism guarantees a full immersion in the simulated scenario, resulting in more efficient and fruitful learning. In this regard, a key role is played by the combination of different levels of technology: physical and virtual.

During the last years, several review studies tried to collect and categorize XR applications in healthcare, especially in medical training and education.

Most studies in scientific literature focused on high-risk, invasive skills related to endoscopy and surgical procedures (Zhu, et al., 2014; Barsom et al., 2016; Meola et al., 2017). Up-to-date reviews, about XR applications beyond surgery, showed that the most frequently studied subjects are within anatomy and anesthesia (Herron, 2016; Gerup, et al., 2020). Several XR applications and prototypes

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involved procedural training, namely a kind of learning that requires activity repetition (Koziol, et al., 2012). A noteworthy example is the one by Kotranza et al. (2012). Authors developed a mixed reality (MR) environment (physical manikin + virtual reality) for teaching clinical breast examination, focusing on enhancing learner communication skills. The system processes student's gestures and motions applied to the task trainer (equipped with force sensors), and the virtual patient provides real-time feedback by appropriate responses, showing anxiety and distress. Kobayashi et al. (2017) developed, for acute care procedure training, an XR application that overlaid (through Hololens®) task-relevant anatomy images over the skill trainer. Indeed, one reason to use AR is to help the user having a visual of the patient's internal body state, interactively (Sherstyuk, et al., 2011). The authors claimed that the manual overlay and registration process was the main technical limitation of the work. Rochlen et al. (2017) developed an AR application for the training of needle insertion for the specific procedure of central venous catheter placement. Using the smart glasses Epson Moverio BT-200®, they projected the relevant internal anatomical landmarks over the skill trainer. The system resulted usable and feasible; however, some constraints were found in the alignment of images and glasses fit. Margarido Mendes et al. (2020) developed a system to pinpoint the insertion of the intravenous needle for central venous catheterization. This system supported not only the projection of internal anatomy over the skill-trainer but also geometrical information about the position and orientation of the needle. Results showed that the new AR system was suitable to complement the conventional training, however, some drawbacks emerged: the tracking system was affected by external factors (e.g. light), the virtual elements were not stable, the head-mounted display caused discomfort, and had a limited field of view.

As resulting from the above-mentioned scientific literature, one of the principal drawbacks of using AR systems in training activities is related to the technology itself. However, the XR advanced interactive training in healthcare education still presents some methodological weaknesses that can be summarized in two main points:

- Lack of explicit pedagogical theoretical framework and comprehensive methodology to guide the design and application of traditional learning strategies supported by advanced technology (Zhu, et al., 2014);
- Use of XR technology mainly to provide additional visual material, which is not available in real practice. The core of most studies in the literature is often the use of XR as an aid in procedural training, giving information about what learners cannot see. However, in this way, the simulation moves away from reality. In aviation, studies observed that pilots trained with this additional information learn to fly more quickly but they become dependent on it and, in the real flight deck, they could not perform as well as those trained without such guidance (Seagull, 2012). This could be a reason why it is not convenient to add the patient's interior organs.

This paper aims to address these weaknesses by proposing a simulation design method that integrates all the relevant elements concerning the design of the scenario and the development of the XR prototype.
Two different technological solutions are proposed and compared.

3 SIMULATION DESIGN

A complete framework for the design of any kind of advanced clinical simulation has been defined (Figure 1). It is suitable for both transversal (e.g., emergency room) and specialized skills (e.g., catheter insertion, pericardiocentesis) simulations, with or without the XR integration. Indeed, the framework is composed of different modules and sub-modules that must be individually considered based on the simulation type and purpose.

Firstly, the learning goal must be set. Then, the real medical procedure must be described by the framework submodules. As already explained in a previous authors' work (Brunzini et al., 2019), it means to design the simulation scenario:

- Features definition: the simulation features must be defined in terms of environment characteristics (location, layout, etc.), clinical actors (profile, role, etc.), patient anamnesis (characterization of clinical scenarios for the diagnosis and management of different conditions);
- Tasks definition: characterization of each task to be performed by the learners, considering verbal and physical interaction with the patient, potential side effects and complications, clinical risks associated with different treatment options, and patient management;

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- Feedbacks definition: characterization of feedback to be given by physical systems (sounds coming from the manikin, ECG signal shown on the monitor, etc.) and/or virtual systems (holograms related to patient parameters, body anatomy details, etc.).

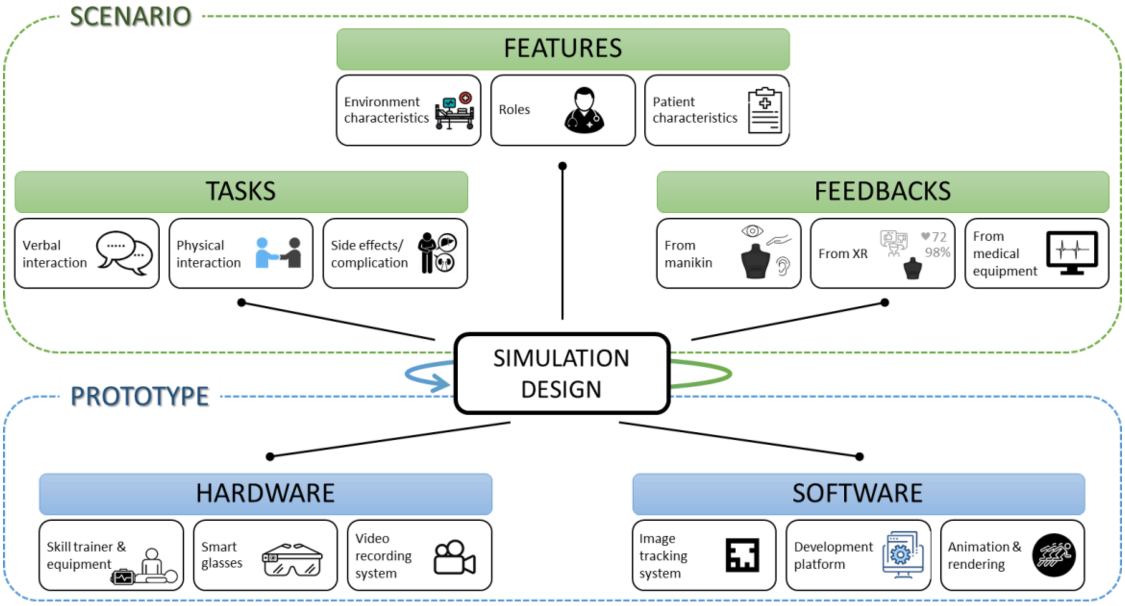

Figure 1. Framework for the design of medical simulations

Once all elements have been defined, for each of them it should be specified if it must be real, virtual, or both. Moreover, the correlations between different elements should be defined to generate an event-driven simulation. For example, when the learner performs a specific task (in a specific environment and on a specific patient), he/she could make a mistake that could generate complications for the patient (shown on the manikin, and/or on the monitor, and/or as a virtual element); based on this event, the intervention of a specific actor or the supply of specific feedback (real, virtual, or both) should be activated.

Then, for the design of the prototype that allows simulating the designed scenario, it should be selected:

- The hardware: manikin and equipment suitable for the simulation purpose, and the potential XR device and video-recording system.
- The software: XR development platform, tracking system, animation, and rendering software.

It is thought of as an iterative approach since the prototype design allows reviewing the scenario and so on until the simulation design satisfies the requirements needed to reach the learning goal.

4 DEVELOPMENT OF THE MIXED REALITY SIMULATION

In this section, the design and development of an XR simulation system for the rachicentesis procedure are described. Rachicentesis is a lumbar puncture type whit the aim of taking a cerebrospinal fluid (CFS) sample to be analyzed for diagnostic purposes. It may also have the therapeutic purpose of draining any liquor excess. Thus, rachicentesis is a surgical technique that involves inserting a thin needle into the space between the arachnoid meninx and the pia mater. This insertion occurs between the third and fourth lumbar vertebrae or more commonly between the fourth and fifth. For the execution of this procedure, the patient can lie in the lateral fetal position or sit on the bed with the back arched forward. Rachicentesis requires maximum asepsis because, with this maneuver, the internal space of the central nervous system is put in communication with the environment. The goal of the simulation is to learn how to perform rachicentesis and become able to let the liquor spilling out. Indeed, if the needle is non-inserted in the right place and with the right depth, the CFS would not come out.

Given its nature, the rachicentesis cannot involve actors simulating patients, which is a successful strategy in medical education (e.g., blood sampling procedure), making it an excellent candidate for XR applications, in addition to the multiple purposes for which is used. Furthermore, the same framework, developed for the rachicentesis and described below, can be easily adapted to similar medical procedures such as pericardiocentesis and thoracentesis.

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4.1 Scenario Design

The XR system for the rachicentesis procedure has been designed following the framework proposed in Section 3. Figure 2 shows the choice between virtual and/or real for each simulation's feature, task, interaction, and feedback.

Learning goal		Rachicentesis procedure								
Environment characteristics		Abdomen skill-trainer lying on a desk; on the right all the equipment and instruments (such as needle, latex gloves, sterile cloth, disinfection swab, test tube) ☐V ☑R								
Roles		Anaesthetist (learner) ☐V ☑R; Patient (manikin) ☑V ☑R								
Patient characteristics		Normal BMI; Obesity; Pregnancy ☑V ☐R								
Task		**Verbal interaction**		**Physical interaction**		**Side effects, complication**		**Manikin feedback**	**XR feedback**	**Equipment feedback**
T1	☐V ☑R	No	☑V ☑R	No	☐V ☐R	No	☐V ☐R	No	Yes	No
T2	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	Yes	Yes	No
T3	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	Yes	No	No
T4	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	No	No	No
T5	☐V ☑R	Yes	☑V ☐R	Yes	☐V ☑R	Yes	☑V ☐R	Yes	Yes	No
T6	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	No	No	No
T7	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	Yes	No	No
T8	☐V ☑R	No	☐V ☐R	No	☐V ☐R	No	☐V ☐R	Yes	No	No
T9	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	No	No	No
T10	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	Yes	No	No
T11	☐V ☑R	No	☐V ☐R	Yes	☐V ☑R	No	☐V ☐R	No	No	No

Figure 2. Rachicentesis scenario (V=virtual and R=real)

The simulated procedure can be divided into eleven consecutive tasks (T) (Figure 3):

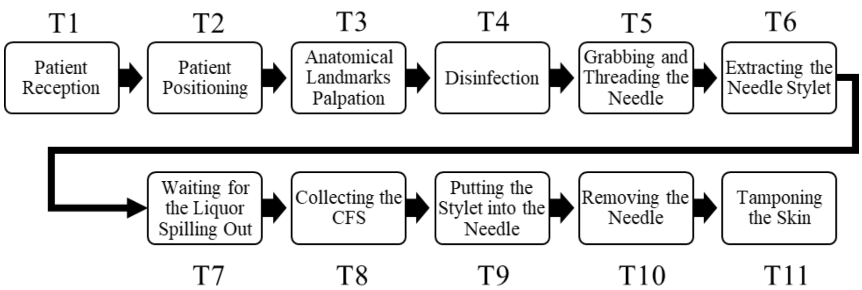

Figure 3. Tasks of the rachicentesis procedure

For each task, the verbal and physical interactions between student and skill trainer, the possible side effects and complications, and the feedbacks (tactile, visual, and auditory) useful to improve the simulation realism are selected and reported in Figure 2.

The simulation is designed to take place in a classroom, at the Faculty of Medicine of Università Politecnica delle Marche, equipped with an abdomen skill-trainer lying on a desk. The manikin can be placed in left lateral decubitus or sitting positions. On the right of the manikin, all the equipment and instruments useful for the procedure (such as needle, latex gloves, sterile cloth, disinfection swab, test tube) should be provided. The student is supposed to individually act as an expert anaesthetist, and the patient could have different physical characteristics (e.g., normal BMI, obesity, pregnancy) that may affect the outcome of the procedure. These body features can be represented and changed at the teacher's discretion through the AR application. The patient anamnesis is not relevant for this kind of simulation.

Therefore, to go beyond the state of the art, an MR application (physical + AR) has been designed and developed to carry out the following main functions:

- To overlay the entire patient 3D digital model on the physical manikin. Indeed, the skill trainer consists only in the patient's abdomen (Figure 4a).

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- To track the needle position during the operation, to provide visual and auditory feedback based on the action performed. In particular, when the student inserts the needle into the manikin, the AR patient complains and has a spasm.

In this way, the learner receives feedback from the simulated patient, as it would happen in reality. Indeed, the purpose of the MR application is not to facilitate the operation, but to "immerse" the trainee in a more realistic environment, which puts him/her under pressure during the exercise, as in real practice.

4.2 Prototype Design

According to the proposed design framework, hardware and software have been defined. The selected manikin was the Gaumard® Lumbar Puncture Trainer (Figure 4a). Its anatomic features include iliac crests, lumbar vertebrae L2-L5, ligamentum flavum, epidural space, the skin layer, subcutaneous layer, and connective tissue. It provides realistic tactile feedback, and lifelike needle resistance combined with a fluid pressure system, that allows the liquor to spill out and to be collected. Thanks to these characteristics, it can be used for the simulation of the needle insertion between vertebrae, injection of local anesthesia, lumbar puncture, epidural, and rachicentesis.
For the AR application, after a wide benchmarking, two devices have been selected and compared: the headset for smartphone Vox Gear Plus® (Figure 4b) and the Microsoft Hololens® (Figure 4c). Their characteristics place them at the antipodes in the current technological panorama, both in terms of technical features and costs.

Figure 4. Mixed reality system hardware: (a) Gaumard® Lumbar Puncture Trainer, (b) Vox Gear Plus, (c) Microsoft Hololens

Vox Gear Plus® is a low-cost headset for the smartphone. It does not have an own computing power but can only be used in combination with a smartphone, on which the application is launched. Vox Gear Plus, holding the smartphone in front of the user's eyes, gives the feeling of three-dimensional visual, using appropriate lenses. This type of device is generally used for virtual reality (VR) applications; however, it is possible to use it for AR applications, using the camera of the smartphone in a see-through manner. This allows the user to see the reality in front of him/her adding the virtual elements on the screen. Microsoft Hololens® is a technologically very advanced device. Indeed, with Hololens the user does not look at a screen, but he/she can see the environment populated with holograms. Hololens are transparent glasses, able to generate small holograms in front of the eyes of the user, who thus has the sensation of seeing a life-size hologram in front of him/her. Concerning the sensors onboard, in addition to the classic accelerometers and magnetometers, Hololens has a special camera (derived from Microsoft Kinect®) able to reconstruct the 3D structure of the surrounding environment. However, the field of view (FOV) for the holograms' visualization is only 30°. The development of the AR application, usable with both devices, followed the workflow shown in Figure 5.

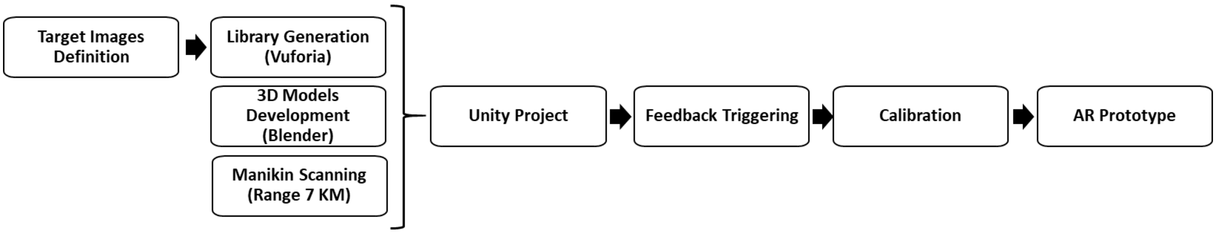

Figure 5. Software development workflow

In particular, the following software has been used:

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- Vuforia, a software development kit (SDK) for AR that uses computer vision technology to recognize and track the position of target images and 3D objects in the space. In this application, Vuforia was used to track the position of two target images: Patient and Doctor.
- Blender, a 3D computer graphics software used to create animated films, visual effects, 3D models. It was mainly used to create the 3D virtual model of the patient, and the related animations.
- Unity, a multi-platform graphics engine, can be used to create multimedia content, games, simulations, both in 3D and 2D. It is used to create the AR scene.

The target images were created using an online free tool that generates images rich in features, that Vuforia can easily recognize. The images were then uploaded in Vuforia to generate the libraries to be imported into Unity for tracking. During the upload, it is necessary to indicate the real dimensions of the physical targets to be tracked.
For the development of the AR patient, a 3D digital model of a woman and the texture were respectively downloaded in .obj and .mtl file formats, from an open-source database. These models are generally supplied in the upright, open arms position to be modified by users according to their needs. Based on the rachicentesis procedure and the manikin's usage configurations, the 3D model of the patient was then repositioned, in Blender, in the left lateral decubitus and sitting positions. In the texturing phase, a "smooth" filter has been used on the 3D model to round the edges of the mesh. In this way, the user does not have the impression of watching a polygonal model. Then, the model was animated to simulate the spasm due to needle insertion. The process output is a .fbx file to be imported in Unity.
To ensure the perfect dimensioning of the virtual model over the skill trainer, the Gaumard® Lumbar Puncture Trainer was scanned by a non-contact 3D laser scanner (Konika Minolta® Range 7) to create a virtual counterpart.
All the steps described above have been put together in Unity to create the main scene of the application, which contains the following two main lots:

- Patient-related lot: it contains the Patient Target Image that is integral with the rachicentesis manikin, and therefore it is fixed on the desk. The "extended tracking" option is activated to avoid the target image goes outside the user's field of view while he/she focuses on the manikin. This means that, even if the target image is no longer in the user's field of view, the system, based on the available sensors, hypothesizes its position and continues to overlap the virtual model to the manikin. The virtual model of the patient includes a "Collider" for the movement triggering and a "Depth Mask" in correspondence with the operation area so that the user can always see through it the operation area on the real skill trainer;
- Learner-related lot: it contains the Doctor Target Image, which is fixed, during the rachicentesis procedure, to the learner's hand through adhesive tape. It includes a "Collider" to trigger the needle-manikin interaction, and a "Depth Mask", integral with the learner's hand, that allows always seeing the hand during the execution of the procedure (otherwise, the hand could be covered by the virtual image of the patient).

  The "occlusion" issue is well known in the field of AR, but neither advanced devices, such as Hololens, are yet able to completely solve it. Indeed, although Hololens is equipped with a depth sensor capable of mapping the surrounding environment, it is deactivated for distances below 0.5m from the device, since it is not able to track the hands' position in real-time.

Movement and auditory feedbacks have been provided to enhance the sense of realism. The animation (i.e., the spasm movement of the patient) is triggered by the contact between the two colliders, namely when the student touches the manikin with the needle during the simulation. A C# script in Visual Studio has been developed for the triggering. Also, audio files reproducing the patient's laments, and complaints were randomly played.

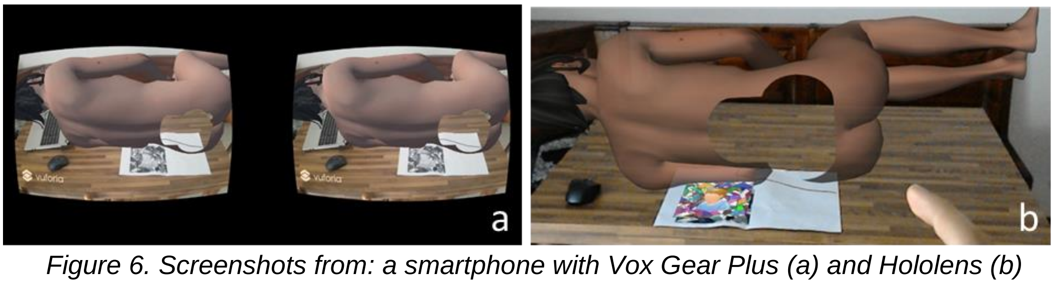

Figure 6. Screenshots from: a smartphone with Vox Gear Plus (a) and Hololens (b)

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Finally, a calibration sheet should be used to ensure the precise superimposition of the virtual patient over the real skill trainer.
As anticipated, the prototype of the AR application has been designed and developed to be used with two different devices. Figure 6 shows the different visualization of the AR model through the Vox Gear Plus (a) and the Hololens (b).

5 RESULTS

After the explanation of the study and MR simulation with the eventual contraindications, eighteen students of the 6th year of Medicine and Surgery Course (55.55% men; 44.45% women; 25.6 ± 0.6 years old) signed the informed consent and took part in this pilot study.
83.33% of them were working on a degree thesis pertinent to the rachicentesis simulation and 38.89% have already had a previous experience with invasive procedures. Most students (more than 72%) were familiar with the use of everyday life technological devices (computers, tablets, etc.) and 55.56% of them were used to play with simulation videogames and were familiar with the use of head-mounted displays. 61.11% of students felt suitable to work in a high-tech environment, and only 22.22% of them would feel stressed working in it. Before performing the simulation, technological devices (e.g., VR glasses, gloves with haptic feedback), multisensory interaction (tactile, visual, and auditory), and virtual feedback were considered useful tools for learning during training by most participants (more than 70%). Moreover, a high degree of immersion during the simulation was thought to have a positive effect on learning (94.44%) and psychological component (88.89%).
The eighteen students performed the MR simulation both with the Vox Gear Plus and the Hololens. They were divided into 3 groups of six students each, so that, for each group, in turns, one student performed the rachicentesis while the other five participants looked at him/her. All the students, after having performed the rachicentesis simulation in MR, with the two devices, repeated it in the low-fidelity manner (without the AR application, only with the manikin). At the end of the three executions, a semi-structured survey for the assessment of user experience was administered. Results in Table 1 show the mean values calculated for both devices.

Table 1. User experience about the use of AR in simulation training

	Hololens	**Vox Gear Plus**
AR use has increased the feeling of immersion and involvement compared to the use of the manikin alone [5-points Likert scale]	3,00	3,82
AR field of view is satisfying for the simulation execution [5-points Likert scale]	2,64	3,53
AR allowed me to carry out checks and actions that I could not do with the only physical manikin	Yes: 24% No: 76%	Yes: 29% No: 71%
AR prevented me from carrying out checks and actions that I could carry out with the only physical manikin	Yes: 18% No: 82%	Yes: 35% No: 65%
AR made the operation more difficult	Yes: 41% No: 59%	Yes: 76% No: 24%
Which feedback have you found effective?	Visive: 94% Auditory: 24%	Visive: 96% Auditory: 20%

Therefore, although the use of both devices in the MR simulation increased the feeling of immersion and involvement with respect to the low-fidelity simulation, the use of Vox Gear Plus was more appreciated from the immersion point of view. Vox Gear Plus also has a more satisfying field of view with respect to Hololens. The percentage of students who thought that AR allowed to carry out checks and actions that could not be done with the only physical manikin is under 30% for both devices. However, while 18% of students who used Hololens stated that AR prevented them from carrying out checks and actions that could be done with the only physical manikin, the percentage rises to 35% for students who used Vox Gear Plus. In the same way, while 41% of students who used Hololens declared that AR made the procedure more difficult, for the same topic the percentage increases to 76% with Vox Gear Plus. Finally, no great difference emerges between the devices regarding the most effective and useful feedback: the visive feedback is preferred against the auditory feedback with a percentage over 90%.

Hereafter, the main advantages and drawbacks of both devices are outlined (Figure 7). Vox Gear Plus gives the user the impression of being immersed in the virtual world, leaving the opportunity to actively interact with the surrounding real environment. However, it presents several limitations that prevented the procedure from being carried out. In particular, the smartphone is equipped with a single camera and thus is unable to record the real scene in a stereoscopic manner. Therefore, the user sees the same duplicated images in front of the left and right eyes, losing the sense of depth. Moreover, the smartphone uses accelerometers to perform the extended tracking, and thus to estimate the AR patient's position based on the movements of the user's head, once the target has been lost. Unfortunately, this technique has limited accuracy that leads to the disappearance or misalignment of the 3D AR model when the patient's target gets out of the user's Field of View (FOV) for long periods.

Vox Gear Plus PRO	Vox Gear Plus CONS
• Feeling of operating on a real patient • Very immersive and realistic • Actively interaction with the surrounding real environment • Attention also shifts to the patient with whom interact • Light, ergonomic, and comfortable device	• Loss of Depth • Difficult eye-hand coordination: it is difficult to find an area, always free from obstacles, on which positioning the target • Limited accuracy for patient tracking • Device obstruction • Nausea and dizziness
Hololens PRO	**Hololens CONS**
• The vision of the whole body helps to orientate the user • Feeling of three-dimensionality • Realistic patient engagement • Ergonomic device	• Attention was sometimes caught more by AR itself than by the procedure • It is initially difficult to get used to • Narrow FOV: it focused the procedure on a specific area, forcing the user to move his/her head to see the rest of the AR patient's body • Slow Needle Tracking • Device physical bulk

Figure 7. Pro and cons of Vox Gear Plus and Hololens

The use of Hololens allows to solve some of the issues highlighted for the Vox Gear Plus:

- Patient tracking: Hololens are equipped with depth sensors that allow, in a few moments, to reconstruct a relatively detailed mesh of the surrounding environment. Thanks to this and other features, the tracking of fixed elements in space is optimal, even after losing the image target from the user's field of view, for a long time.
- Depth Perception: Hololens allows seeing through the lenses of the device. The vision is stereoscopic, and the depth perception is optimal.

However, Hololens also presents various limitations. The main one is related to the narrow FOV, which is only 30° x 17.5°. It means that only a small rectangle in front of the user can be populated by holograms. Consequently, during the rachicentesis simulations, the area available to view the 3D AR model of the patient is that of the real manikin, which, therefore, at a close distance, will never appear complete. The user is forced to move his/her head to see the rest of the AR patient's body, thus reducing the sense of realism and immersion.

As anticipated, it was impossible to complete the rachicentesis procedure with Vox Gear Plus. Therefore, performance refers to the MR simulation accomplished with Hololens. The mean number of attempts to reach success (i.e., learners were able to make the liquor spilling out) was 2.21 (± 2.03), and the mean number of errors per subject was 0.33 (± 0.49). The success rate, which was equal to 94.45%, and the mean execution times were comparable with those of the traditional procedure.

6 CONCLUSIONS

This pilot study allowed the understanding of the user experience related to the use of an MR simulation system, developed according to a structured framework. It also permitted to highlight the differences between the two solutions, in terms of device acceptability, and simulation execution. Despite the highlighted technological limitations, the practitioner instructor suggested the use of the MR simulation for the degree of immersion that it provides, allowing practicing in a situation as similar as possible to

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the real one. Preliminary results confirm the great potential of extended reality as a support tool for the medicine of the future, both for medical education and when performing procedures.

Future work will focus on the statistical analysis of MR effectiveness based on a significant sample of learners. Indeed, studies in the literature were conducted only on small cohorts of participants (Munzer, et al., 2019), statistical analyses reported incomplete or misinterpreted results (Gerup, et al., 2020), and rigorous, objective measurements of clinical procedural skills and human performance metrics continue to be very limited or absent (Linde, et al., 2019). Another aspect that will deserve more investigation is the educational utility of this kind of system, compared to traditional training and simulation.

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