Development of a Real-Time Adaptable Virtual Reality-Scenario Training for Anaesthesiology Education, a User-Centered Design

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Abstract: Simulation training in medical settings has become pivotal in clinical education. Virtual reality (VR) presents a novel approach to simulation, offering numerous advantages for both trainers and trainees by facilitating high-fidelity practice in situational awareness, decision-making, and multitiered response systems within a safe yet stressful environment. This paper outlines the development of a multiplayer VR simulation prototype tailored for anaesthesiologist-intensivists, with input from a multidisciplinary expert team throughout the process. Trainers can dynamically adjust patient physiological parameters, enabling training in crisis resource management under pressure. Following a user-centered design (UCD) methodology, iterative design cycles involve experts adapting a Failure Modes and Effects Analysis (FMEA) to prioritize trainee and trainer needs. User feedback, gathered through various qualitative and quantitative UCD techniques such as interviews, focus groups, and prototype testing, informs each iteration. Three simulation prototype versions underwent evaluation, incorporating simulation settings, debriefing sessions, and FMEA analysis. Feedback informed iterative design improvements until thematic saturation was reached, culminating in the creation of an initial prototype. This paper aims to detail the development process of a VR scenario training program, geared towards immersive simulation learning.

1 INTRODUCTION

One of the cornerstones of medical training is clinical scenario training using an environment to learn effectively (Anthony, 1996; Yunoki & Sakai, 2018). Simulation based learning provides a safe learning space where healthcare providers can gain experience on medical emergencies or rare complications in a controlled setting without putting real patients at risk.

Especially for anaesthesiologists/ intensivists, management of a patient who is acutely deteriorating requires excellent technical and non-technical skills in a highly stressful and chaotic environment. Technical skills may include tracheal intubation, difficult airway management, vascular catheter placement and regional anaesthesia. Also, sufficient medical knowledge of differential diagnoses, drug dosages, triages of possible actions, and crisis resource management are crucial and may be lifesaving. Situation awareness, decision making, teamwork, communication and leadership are indispensable skills in clinical practice outlining the importance of human factors (Institute of Medicine Committee on Quality of Health Care in, 2000). Improvement in patient outcome may come from multitiered rapid response systems.

Knowledge is constructed in social contexts and students need to be active learners rather than passive recipients of knowledge (Anthony, 1996). Although several studies have shown the effectiveness of simulation-based training over the last decade (Dorozhkin et al., 2017), increasing pressure son budget and logistic limitations, needs for alternative methods of simulation have emerged. Also, current simulation programs may not have scenarios with

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real-time adaptation possibilities which are seemed to be required in order to create an immersive environment with unlimited training possibilities for personalization of the scenario (Bracq et al., 2019; Tursø-Finnich et al., 2023; Yunoki & Sakai, 2018).

Immersive Virtual Reality uses a Head-Mounted-Display (HMD) project in front of the eyes allowing users to focus on display without interaction of the outside world. It offers novel capabilities providing new qualitative support for educators and trainees as it can be used independent of geography, time and space, and it is cost-effective (Pottle, 2019). Immersive VR can produce a visceral feeling of being in a simulated world, a form of spatial immersion called Presence (Fuhrt, 2008; Pottle, 2019)Also, in virtual interactions, participant's avatars can affect their attitude, perception and behaviour in a conscious or unconscious matter known as the Protheus Effect (Bian et al., 2015; Navarro et al., 2022). However, there are also potential drawbacks such as limited haptic (tactile) feedback (Ruthenbeck & Reynolds, 2015) and the absence of non-verbal cues in the trainees' digital avatars (Pottle, 2019).

The main objective of this study is to develop a prototype of a VR-scenario training program for anaesthesiologists-intensivists. The VR-scenario training program is tailored to the needs and experience of the trainees and simulation trainers with a multidisciplinary expert team involved throughout the development process and guide all design decisions. This paper will describe the development phase of our prototype.

2 METHODS

2.1 Study Design

We've adapted a user centered design as it employs scientifically proven methodologies of human sciences to optimize designs of human-technology interface improving its proficiency and performance and is easy to use (Walden et al., 2020).

During the development phase, three simulation prototype iterations were made, each evaluated with a simulation setting, debriefing and Failure Modes and Effects Analysis (FMEA) (Davis et al., 2008). After every simulation, feedback was provided to the development team responsible for the VR environment. This feedback loop encompassed evaluation of the simulation setting, debriefing sessions, and analysis through FMEA. The VR developers then utilized this feedback to iteratively enhance the VR simulation. Subsequently, design iterations were made, and the modified prototype underwent testing and adaptation until thematic saturation was achieved. We adapted FMEA as it identifies possible system failures and vulnerabilities in complex processes to make a system more robust before an adverse event or problem occurs (Davis et al., 2008). It is a method to identify parts of the process most in the need of change. A multidisciplinary expert team for the FMEA process was selected including 5 steps: (1) team selection, (2) process identification, (3) process flow diagram preparation, (4) failure mode identification, and (5) determination of an action plan.

For the evaluation phase which is beyond the scope of this article, we will assess content validity through qualitative and quantitative measures in an exploratory sequential design.

2.2 Participants and Setting

The protocol was approved by the Institutional Science Committee of the Anaesthesiology science department and obtained a waiver from the Institutional Review Board (NWMO-LUMC).

Informed consent was obtained prior to inclusion, participation was voluntary and privacy rights were in alignment with the Declaration of Helsinki and GDPR guidelines. The multidisciplinary expert team for the FMEA process was designed to include anaesthesiologists-intensivists, trainers, human factor specialists and software VR design technical experts. Participation was voluntary. Exclusion criteria included physical incapacity to use VR which was not encountered during the study. Participants did not receive a financial compensation.

2.3 Sample Characteristics

Three healthcare providers participated of whom one the project manager. Two were anaesthesiologists-intensivists, one was a resident. Together with two developers and one experienced researcher they assembled as the multidisciplinary expert team for the FMEA process.

2.4 Conceptual Framework

Commonly, simulation consists of three components: an initial briefing with explanation of the upcoming scenario, the simulation experience and a debriefing where learners are provided with a crucially important opportunity to reflect on themselves and their team in order to improve future practice (Pacheco Granda & Salik, 2023).

Today's VR simulation programs often use preset scenarios put into practice (Bracq et al., 2019; Brammer et al., 2022; Macnamara et al., 2021). Standardized patients (SPs) or standardized scenarios have been utilized for procedural skills assessment and non-technical skills development.

According to the principles of Cognitive Load Theory (CLT) (Reedy, 2015), there is a limit on how much information one can process simultaneously, impacting the information storage and retrieval. A trainer may not know beforehand how the trainees will perform during the scenario; hence he/she may not know beforehand how they want the scenario to evolve. This outlines the importance of the adaptability of a scenario, enabling a more effective and valuable learning experience.

We've hypothesized our real-time adaptable VR-training program could fill in this gap as we wanted to create a program where a trainer could change the scenario in real-time.

2.5 Data Collection and Analysis

User feedback was collected through various qualitative and quantitative UCD techniques including contextual inquiry, interviews, focus groups, observations, questionnaires, walk-throughs and prototype testing.

3 RESULTS

Three simulation prototypes underwent evaluation by the multidisciplinary expert team encompassing FMEA sessions. An example of a FMEA session can be found in Table 1.

3.1 VR-Simulation Requirements

The VR- simulation was designed to be a fully immersive reality system, with auditory, visual, and tactile feedback, in real time adaptable by the trainer. This implies scenario's to be adaptable online, during the simulation. Patients' clinical presentation (skin color and rash, pupil dilation etc.), and paraclinical presentation (arterial tension, pulse oximetry, bispectral index measurements etc.) were available on the trainer's dashboard enabling a fully adaptable simulation training.

With an initial analytic phase of the UCD design, the multidisciplinary expert team produced a list of basic requirements divided in five major themes as shown in Table 2. The use of the MoSCoW prioritisation technique further classified these requirements (Miranda, 2022).

Table 1: Failure mode simulation session two.

Concern	Severity category	Potential Active Failure	Action plan
Latency	Perfor-mance impact Participant experience	Potential Active Failure	Purchase powerful server.
Bumping into each other	Perfor-mance impact	Dizziness	IT adaptations within the VR.
Telepor-tation	Participant experience	Failure to immerse	Testing of different standalone HMD with limited space.
Onboard-ing	Perfor-mance impact	Physical	Use of standalone HMD without teleportation option,
Onboading	Participant safety	Failure to immerse	Virtual onboard area with tutorial

Table 2: Basic requirements.

Visuals patients	Patient morphology, age sex Anatomic details (facial hair, neck size, chin size, intra-oral anatomy)
Visuals avatars	Automated avatars Hand and eye movement
Visuals surgery	Laparoscopy Laparotomy
Equipment OR	OR table OR lights Respiratory machine Anesthesiologic equipment Surgical equipment
Multiplayer	1-5 players
Trainer dashboard	Adaptability of medical conditioning

The static requirements consisted of materials including airway devices, medication, and infusion equipment, as well as operating room equipment such as the operating table, lighting, and anaesthesiologic and surgical instruments used for procedures such as laparoscopy and laparotomy as shown in Figure 1.

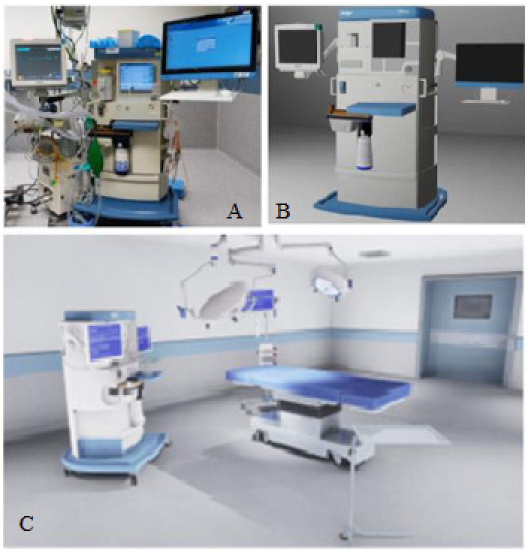

Figure 1: View of a photo (A), the digital design (B), and the incorporation in the virtual OR environment (C).

Requirements of the visuals of the patients were morphological features as shown in Figure 2. Anatomic details such as facial hair, neck size, chin size, intra-oral anatomy needed to be well designed to enhance a high level of fidelity.

Figure 2: View of a patient with high resolution facial details.

Furthermore, dynamic requirements encompassed procedures such as intubation, both standard and alternative techniques, and the placement of intracorporal catheters such as an intravenous line, intra-arterial catheter, stomach siphon, or central venous catheter.

Additional dynamic requirements included patient positioning, administration intravenous (IV) medication, and other related considerations. An extensive overview of these items can be found in the Appendix.

3.2 VR-Simulation Requirements

The multidisciplinary expert team employed a collaborative approach to construct flow diagrams to depict dynamic interactions of which an example is depicted in Figure 3. This iterative process involved the utilization of various media, such as videos captured in the operating room, detailed descriptions, and photographs, among others, to facilitate communication between the different parties involved.

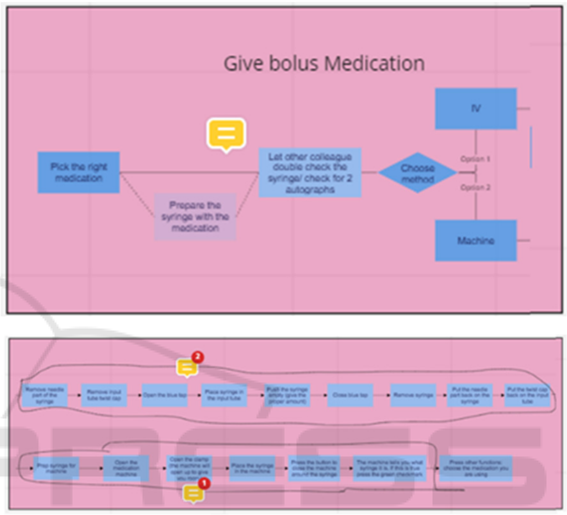

Figure 3: View flow diagram of a bolus gift medication.

4 DISCUSSION AND CONCLUSION

This paper provides useful information on the development of a prototype of VR-scenario training program with the potency of experimental learning with VR. It may contribute to further research and healthcare educational programs avid to use immersive simulation learning with VR. A real-time adaptable program may fully optimize learning processes and adds flexibility within the scenario's.

Future research on the prototype, employing UCD techniques, is crucial to further validate its effectiveness through iterative cycles of evaluation, utilizing Kirkpatrick's evaluation model (Cannon-Bowers, 2008; Falletta, 1998; Smidt et al., 2009). This evaluation model assesses the prototype's potential impact on four levels: (a) participants' reaction to the training, (b) participants' learning outcomes from the training, (c) participants' behavioral changes resulting from the training, and

(d) the subsequent organizational impact stemming from participants' changed behavior. Additionally, it also considers (e) the economic benefits or overall human welfare derived from the training (Cannon-Bowers, 2008; Falletta, 1998; Smidt et al., 2009).

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APPENDIX

This appendix gives an extensive overview of the static and dynamic requirements of the VR simulation.

The requirements are annotated with the of the MoSCoW prioritisation.

Static requirements included anaesthesia supplies, airway supplies, operating room supplies, surgical procedures.

Table 3.

STATIC	
Anaesthesia supplies	
Must	Intravenous infusion (IV) sets in pink, green, blue, yellow, and orange
Should	Subcutaneous needle
Could	Tape
Will not have	Intravenous deep catheter
Airway supplies	
Must	Size 6 oropharyngeal tube
Should	Size 7 oropharyngeal tube
Could	Size 8 oropharyngeal tube
Will not have	Size 3 laryngoscope
Operating room supplies	
Must	IV stand
Should	Infusion pump filled with syringes
Could	ECG electrodes
Will not have	Blood pressure cuff
Surgical procedures	
Must	Laparotomy (in supine position): vertical incision
Should	Laparoscopy (in supine or (anti)Trendelenburg)
Could	Laparotomy in pregnant patients (horizontal incision)
Will not have	Limb surgery

Table 4.

DYNAMIC	
Anaesthesia supplies	
Must have	IV infusion sets in pink, green, blue, yellow, and orange
Should have	Subcutaneous needle
Could have	Tape
Will not have	IV catheter
Airway supplies	
Must have	Size 6 oropharyngeal tube
Should have	Size 7 oropharyngeal tube
Could have	Size 8 oropharyngeal tube
Will not have	Size 3 laryngoscope
Operating room supplies	
Must have	IV stand
Should have	Infusion pump filled with syringes
Could have	ECG electrodes
Will not have	Blood pressure cuff
Surgical procedures	
Must have	**Placement of IV line** Applying a tourniquet Finding a visible vein (lightly tapping on vein, asking patient to make a fist) Cleaning the skin Opening IV packaging Placing IV catheter Securing the catheter with tape Connecting IV bag to IV line
	Administration of bolus medication Opening the cap or valve and attaching the syringe Pushing the plunger Administration of continuous medication - Medication is in a pump that is connected to the IV line Selecting "speed" and "amount" of medication, then confirm
	Placement of vital monitoring (after connecting to the monitor, values are also visible on the screen) BIS -Placing BIS stickers on forehead -Connecting to BIS monitoring ECG: Placement of 5 electrodes -Connection to ECG monitoring Blood pressure -Placement of blood pressure cuff -Connection to monitoring Pulse oximeter -Placement of finger probe -Connection to monitoring
	Intubation Preoxygenation with placement of a mask on patient's face Induction of anesthesia: starting medication that causes patient to fall asleep

	Bag-valve mask ventilation Intubation -With laryngoscope -With glidescope -different views: View grade 1, View grade 2, View grade 3, View grade 4, View with vomit grade 1/2
	Positioning: Table in Trendelenburg position Table in Anti-Trendelenburg position Placement of an additional rolled-up blanket under the neck (changes intubation conditions) Placement of arms along the sides Placement of arms on armrests Placement of sterile drapes with attachment to the anesthesia pole
Should	**Placement of arterial line** Palpate for pulses (inside pulse for radial artery) Sterilize the skin Injection of local anesthesia (2cc syringe with lidocaine, subcutaneous needle) Opening of arterial needle from packaging Placement of arterial needle (placement is successful: red blood returns from the hub) Withdrawal of needle Advancement of catheter Close the red cap Cover with tegaderm Connect arterial line Zeroing arterial line (optional)
	Removal of arterial blood Draw blood into arterial line hub Withdrawal of arterial blood Backflush blood from the arterial line hub Flush arterial line
	Warming Placement of upper body or lower body
	Administration of pressure infusion Place the infusion in a pressure bag
	Squeeze the air pump under the pressure bag.
Could have	**Placement of gastric tube** Placement of gastric tube through the nostril Advancement of the tube up to 55cm Suctioning the gastric tube will either show nothing (tube is likely misplaced) or green gastric contents (tube is in the right place) Taping the tube in place
Will not have	**Defibrillation** Placement of defibrillator pads (rhythm visible on defibrillator) Charging the defibrillator with adjustable joules Rhythm check
Should	**Placement of temperature probe** Placement of temperature probe through the nostril Connection to the monitor
Will not have	Placement of central line Placement of urinary catheter Placement of ultrasound-guided IV Placement of ultrasound-guided CVC Placement of ear oximetry Placement of TOF-CUF Measurement of neuromuscular blockade Blood draw from peripheral site Cell-saver Warming Connection to bear-hugger Activation of bear-hugger