Virtual Reality Simulation LUMC

Virtual Reality as a simulation tool for scenario training

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Preface

I would like to offer my gratitude to Krista Hoek, Leiden University Medical Center, and Saxion University for offering me the chance to work on such a captivating and innovative project. Krista offered me the opportunity to explore working within a professional medical environment, thus helping me further develop my communication skills.
Her curiosity and enthusiasm guided the project in interesting directions and maintained a steady energy for the team.

For the help provided during the graduation period I would like to thank my graduation coach, Alejandro Moreno Celleri, teacher at Saxion University. It has been a period filled with uncertainty, and I am thankful for Alejandro's constant support and reassurance.

Lastly, I would like to thank the members of the IMT&S team, Akin Cakiner, Emanuel Velez Cano, Mark Niemeijer, Mihai Dascalescu, Saila Skride, Sanne Waanders and Remco Plas, for collaborating with me and for all the hard work put into bringing this project to a great end.

Abstract

During the graduation period, I have worked with Leiden University Medical Center on bringing to reality the first steps to creating a complementary training tool for their residents. As their motto indicates, '(…) the LUMC stands for the improvement of healthcare and the health of people', and thus the rise of new technologies brought the opportunity to further their means of education by using virtual reality as a simulation tool for scenario training of anesthesiology residents.

I have researched the effect of visual realism in virtual reality simulations, on efficiency of the training and understanding of the tasks and procedures of anesthesiology during scenario training. As a result, together with an IMT&S team, we designed and created a demo application which simulates a kidney transplant surgery and the anesthesia procedure in a virtual operating room. The results of the user tests indicate the potential of using virtual reality simulations as a complementary tool to the real-life manikin used for training.
As such, the demo we created will serve as the first phase in the production of a complex virtual training simulation.

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Glossary

Virtual Reality – VR is a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell, and taste. (Burdea, G. C., & Coiffet, P., 2003).

Unity Engine - Unity is a platform for creating and operating interactive, real-time 3D content, providing the tools to make games and publish them to a wide range of devices. (Unity Platform, n/d)

Global Assessment Five-Point Rating Scale - a 5- or 6- point scoring system used to assess disease severity. (Pascoe, L. B. V. A., 2015)

Manikin - a model of the human body that is used for teaching art or medicine. (Oxford Learners Dictionaries., n.d.)

BiS sensor - The bi-spectral index monitor processes electroencephalographic (EEG) signals to obtain a value, which reflects the level of consciousness of the patient. (Mathur, S., et. al, 2021)

1. Introduction

In medical settings doctors encounter various clinical situations where not only technical skills have to be mastered but also decision making, communication skills and clinical medical reason. Especially for anesthesiologists, crisis resource management and patient safety are fundamental. (Lei C. Palm K., 2020) In the operation room they may encounter live threatening situations where they have to act fast without much room for error, as such, it is essential that the training feels "real" enough to create a completely immersive and realistic scenario.

Currently, medical training is done in various ways, including complex and expensive mechanical human manikins, used for scenario training (Farra, S. L., et al., 2019). However, there are limitations in the real-life simulation practice. This includes the limited options a mechanical patient can simulate during the training. For example, the manikin cannot change skin aspect and color, weight, sex, or age, and it cannot show sweat production, nor speak. The manikin also cannot showcase surgical interventions or broken limbs. According to doctors at Leiden University Medical Center (LUMC), "accurate visual inspection is one of the most important aspects of medical procedures", and therefore, "the lack of these features makes the current manikin less realistic and limits the potential benefit of training".

Given the limiting visuals of the physical manikin and limited accessibility (party due to the COVID-19 pandemic) the **Leiden University Medical Center (LUMC)** would like to explore how VR could be used as an accessible and visually realistic addition to the training of anesthesiology residents.

2. Reason for assignment

2.1. Company outline

LUMC is a modern university medical center for research, education, and patient care, with a high-quality profile and a strong scientific orientation. They contribute to the improvement of medicine and healthcare nationally and abroad. Within the LUMC, students are prepared for a lifetime of innovation and learning, researchers directly test their findings in practice and patients are served according to the most current state of science.
By involving companies and organizations in the region and beyond, the LUMC actually makes innovations and new applications possible, thus performing a pioneering role in developing solutions for health issues. Their vision is best highlighted by their motto:
'As an innovator, the LUMC stands for the improvement of healthcare and the health of people'.

2.2. Graduation Assignment

The Leiden University Medical Center would like to explore how a VR application could be used as an accessible and visually realistic addition to the training of anesthesiology residents. The VR technology substitutes the real world with a computer-generated environment by using a head-mounted display (HMD). This simulated representation of a real-world environment creates a viable training opportunity for any medical situation.

3. Objectives of the client

3.1. Client question

The client's goal is to provide better training opportunities for anesthesiology residents and explore the benefits and drawbacks of using VR compared to the current training practice with a physical manikin.
There are four production phases planned by LUMC in order to structure the progress of the VR training application:

<u>PHASE 1: BUILDING A PROTOTYPE</u>
The prototype will consist of one scenario built to serve as a proof of concept.

<u>PHASE 2: EVALUATION OF THE PROTOTYPE VR SIMULATION</u>
A qualitative research will be performed by analyzing the trained scenarios for their potential efficacy. Semi-structured interviews are used as an outcome measure to evaluate the experience of the participants.

<u>PHASE 3: BUILD AN ADVANCED VR SIMULATION</u>
This advanced VR simulation will be built if the evaluation of the prototype VR simulation has provided promising results.

<u>PHASE 4: EVALUATION OF ADVANCED VR SIMULATION</u>
To evaluate quality and efficacy, LUMC will conduct a mixed method study where qualitative data as well as quantitative data will be evaluated simultaneously. Video-analysis of the real-life simulations is compared with recorded VR simulation for a qualitative analysis. Interviews with participants will also be conducted. A questionnaire is used for a quantitative analysis.

Due to the large amount of subtasks on each phase, I, together with an Immersive Media Technologies and Storytelling (IMT&S) group have been assigned to work on the first phase of the project – creating a prototype of the operating room with the necessary medical equipment and a realistic 3D patient. The chosen scenario for the training is a kidney transplant surgery.

3.2. Limitations

The project presents a number of possible limitations which include:

- Hyper-realistic visual requirements for the environment and 3D patient
- The training simulation must feel “real” enough in order to produce accurate stress levels for the trainees
- Financial limitations in terms of the VR headset choice
- Hardware limitations – whether the training is at home vs specialized training room
- The limited number of participants during the VR simulation
- Trainee VR handling experience

4. Problem analysis

Currently, using a mechanical manikin presents limitations which inhibit proper and extensive training for the anesthesiology residents. Therefore, as a result of technological advancements, VR simulations could enable a better training experience. This technology allows users to experience any situation from multiple points of view, making it a promising, cheaper, and effective tool as it can create a vast variety of medical scenarios. The possibility to practice in multiplayer mode or individually and with a wide range of personnel offers the chance to train even those unable to be trained in the real world.

The use of VR simulations to train technical skills has been studied and validated in surgical settings, for example Ayoub et al. (2019) describes how capturing 3D virtual models of facial soft tissue and hard tissue data for analysis and surgical planning overcame the drawbacks of 2D photographs and radiographs. As such, virtual planning improved the accuracy of inserting dental implants using either a statistic guidance or dynamic navigation.
In another example, Pulijala et al. (2019) examined the application of a haptic-assisted craniomaxillofacial surgery planning system used to restore skeletal anatomy in complex trauma cases. The study showed that haptic feedback provided an additional immersive reality which improved manual dexterity, surgical navigation, and clinical training.

There are various other benefits of using VR simulations instead of mechanical manikins, for example, trainees have the possibility to cooperate over large distances with the ability to implement new training procedures much faster than updating a physical manikin.
VR simulations also allow having a larger training capacity for healthcare workers due to the reduced organizational hazards, as well as overcoming the limited number of available manikins used for training.
Thus, there are a large number of advantages of using VR as a training alterative, however, a very important aspect is the visual realism within the VR simulations. A realistic environment is crucial for the training’s efficacy, and it helps trainees understand the environment and the manikin’s symptoms.
Therefore, as an individual assignment, I will conduct research on the subject of realistic asset creation, the plan being to create a basic VR training scene which will have multiple iterations and levels of realism within. It is important that the training simulation is efficient in the means of asset creation, due to the limited time, but also efficient for training purposes. As such, those iterations will be tested together with the client in order to determine what would be a proper balance between realism and efficiency.

5. Theory

The VR simulation application is intended to be used complementarily to the physical manikin used by the anesthesiology residents. Therefore, data will be collected on previous implementations of VR in medical settings. Research data about the importance of realism within VR training simulations and information about advantages or disadvantages of using VR as a training tool for professionals will be analyzed and compared.

5.1. VR as a training tool

VR offers the ability to experience and train in a realistic simulation without the risk of endangering the life of a person, and it has been used as a training tool as far back as 1960's, when the military engineer Thomas Furness created the first flight simulator for the Air Force. (Mertz, L., 2019) Furness designed a system that projected information such as computer-generated 3D maps, forward-looking infrared and radar imagery, and avionics data into an immersive, 3D virtual space that the pilot could view and hear in real time. The helmet's tracking system, voice-actuated controls, and sensors allowed the pilot to control the aircraft with gestures, and eye movements, translating immersion in a data-filled virtual space into control modalities. (Lowood, H. E., 2020)

Another example would be Shell's deep-water safety training. Shell's workforce stationed at the Malikai project, offshore Malaysia, has a custom-designed VR simulation of the Malikai platform used to train its workers about operational safety procedures. (Shell, n.d.)
Training on a simulated environment is helping technicians deal with potential hazards due to performing unsafe actions and understand the steps to overcome any unforeseen event. (GlobalData, 2020)

5.2. VR used in medical settings

Decisions taken during life-threatening situations in medical procedures can be practiced and refined using virtual training as a risk-free alternative. Thus, the advantage of using virtual reality for corporate training is that it is beneficial to make mistakes and learn from them, for example, a doctor's performance can be monitored and tested to see where real-life changes could be made. Since there is less time pressure in a structured training environment, doctors will think about their choices more carefully in VR training than they would if they were training on the job. When presented with a real-life situation, this will encourage them to make more educated decisions. Therefore, efficient virtual reality training can ultimately save lives. (Lowood, H. E., 2020)

Hospitals and universities around the world have successfully embraced VR-based training for years, and the effectiveness of it can be observed in a study by University of California, Los Angeles (UCLA) David Geffen School of Medicine. The study involved 20 participants which were assigned in two groups, randomized between traditional training and VR training done on the Osso VR platform. Each participant had to perform a procedure to repair a fractured tibia (one of the bones passing between the ankle and the knee). (Osso VR – Virtual Reality Surgical Training Platform, 2020)
Results, as measured by the Global Assessment Five-Point Rating Scale, show that the

participants in the VR group obtained significantly higher scores in all categories compared to the traditionally-trained group, with an overall improvement of 230% in the total score. Figure 2 showcases a graph with results of the various categories tested.
In addition to that, Osso VR-trained participants completed the procedure an average of 20% faster in comparison to the traditionally trained group, while also completing 38% more steps correctly in the procedure-specific checklist. (Harvard Business Review, 2019)

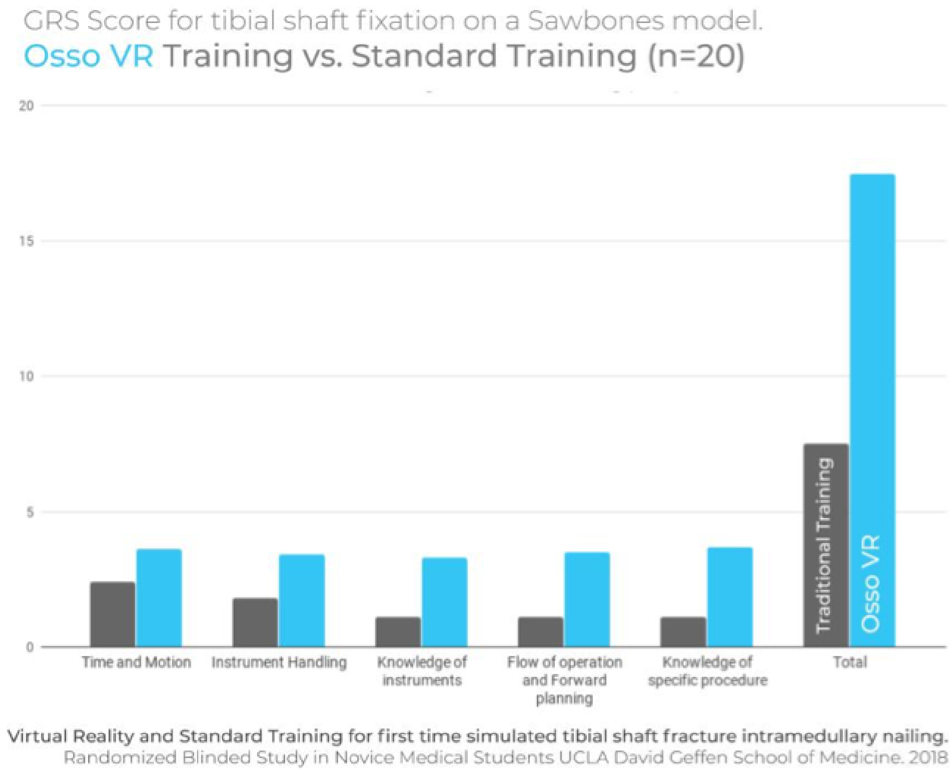


Fig. 1 - *Osso VR. (n.d.). Osso VR training vs. Standard Training [Graph]. Retrieved from https://ossovr.com/*

5.3. Advantages and disadvantages of training medical groups using VR

According to a study conducted by Samadbeik, M. et al. (2018), which collected data from 21 medical articles, using VR has improved learning in 17 (74%) studies. A higher accuracy in medical practice by people trained through VR has been reported in 20 (87%) studies. The findings of the study indicated that the average period of training different medical groups using VR was between six months to one year. Additionally, the application of VR reduced the time required for training medical groups.

Detailed results of this study can be found in **Appendix A**, offering an overview on the advantages and disadvantages of VR in teaching medical groups.

5.4. Importance of realism in VR training applications

Previous sections analyzed how training is done using VR, along with benefits and examples from various fields it has been utilized for. Following up, this section will cover the role of realism and the importance it has in VR simulations. In addition to that, analysis will be done on how fidelity is achieved in simulations and what are the results of different levels of realism in training.

In a paper by Bubser, B. (2019) it is indicated that realism is highly important when the objective is to increase the assimilation of knowledge, skills, and behaviors which are eventually applied in real-world applications.

A scientific journal by Ragan, E.D. et al. (2015) analyzes the results of an experiment which evaluates the effects of fidelity (i.e., realism) in training effectiveness for a visual scanning task. The experiment was conducted with 45 participants, the majority being students from various disciplines, aged 21 in average.
During the evaluation part of the study, the authors found no significant impact of visual realism on target tracking efficiency. However, the study discovered that visual realism has a major impact on both strategy transfer and training task efficiency.

Initially, participants scored much higher in the training stage with lower levels of visual realism, meaning that the simpler the environment was, the easier it was to follow the targets. However, pure performance is not the only important factor to training system designers. Learning the correct procedures, strategies, and skills is also essential and valuable.

As a conclusion, the study suggests using a degree of visual realism that is as close to the real world as possible in training systems for visual scanning and related tasks. A higher level of realism ensures a good understanding and information assimilation, resulting in better trained individuals.

6. Problem definition

The theory has shown that VR simulations are a valuable addition to the physical manikin training, and in order to enable the anesthesiology residents to experience an accurate and improved training simulation, the final application must contain a sufficiently realistic and interactive environment, along with a 3D patient.

The conditions of satisfaction for the final product and client requirements are:

- Visually realistic operating room (OR) and digital patient
- Realistic soft-body physics and fluids
- Correct auditive and visual feedback based on decisions of the trainee
- Interactive functioning of the patient adaptable by the trainer (engineer)

My contribution to the project involves researching and prototyping on the subject of realistic visuals of the VR environment and assets.

7. Main and sub questions

The main research question has been formulated as a result of the data collected in the previous sections:

"<u>How do different levels of realism in props and environment affect VR training efficiency for anesthesiology residents</u>?"

Sub-questions will be used to support and approach the main question:

- How to create realistic, yet optimized, assets that do not affect performance or training efficiency?

8. Scope

To create a realistic environment and manikin in VR, I, together with the IMT&S group, consisting of 7 other students (2 artists, 2 designers, and 3 engineers), must research what are the existing machines used in simulation training, in addition to what actions the manikin should be able to do (such as breathing, bleeding etc.).

Fig. 2 – *Photograph of the manikin used in the LUMC training room.*

These factors can be examined using the field research method, together with desk research and interviews with the client, in order to clarify any uncertainties about the specialized machinery or the manikin.
Following the research stage, we will proceed to create a prototype application containing the necessary machines, environment, and a realistic 3D patient. The assets created by the team will be implemented in the Unity VR application.
At the end of each sprint (lasting around 2 to 3 weeks), a client meeting is organized in order to present the progress and updates. During the client meeting, feedback is collected and any necessary changes and requirements for the final product are recorded.

As a group, the main goal is to deliver a polished demo VR training application. As mentioned in Section 3.1 – Client question, the delivered application will serve as the first phase of the project which will be tested with the residents of LUMC.
My responsibility is to deliver a series of prototypes which contain different levels of realism in the environment and assets. It is important to analyze what level of realism is optimal so that the training efficacy does not diminish while also maintaining performance. Therefore, the student will test different levels of texture quality, poly-count, and levels of detail, with the already created props, in order to compare the data.
A limited number of realism levels will be maintained in order to produce prototypes which can be easily tested and measured (for example, asset texture quality differences between 2K and 4K).

My tasks will not interfere with the animated UI displays of the monitors due to the importance of recognizing each technical parameter (such as pulse, CO2, blood pressure, etc.).

Due to its clear overview and usefulness, I will organize and prioritize the tasks assigned to me and features of the product using the MoSCoW method.
This method's application can be observed in Table 2.

Table 2 - *List of requirements created using the MoSCoW method.*

MUST HAVE	- Anesthesia machine 3D model improvements - Different texture quality levels of the anesthesia machine - Model of respirator mask and filter - Model of BiS sensor - Model of surgical drapes - Model of the vaporizer used for the anesthetic machine
SHOULD HAVE	- High quality textures for the misc. items used in the anesthesia process - Testing different types of VR avatars used by the trainees (e.g., only torso, head, and gloves / full body / only head and gloves, etc.) - Realistic representation of the patient intubation (e.g., how different tubes are attached to the machine and to the patient, based on visual references) - Posed sterile avatars (surgeon) next to the patient - Realistically lit environment, replicating the conditions at LUMC
COULD HAVE	- Testing session with LUMC residents - Testing the pressure of the VR controllers (e.g., syringe pressure resistance) - Testing different VR headsets
WON'T HAVE	- Digital manikin changes - Different texture quality levels for the training room (e.g., walls, floors, ceiling) - Assets unrelated to the surgery or anesthesia process (stools, information boards, trashcan, etc.)

9. Implementation

9.1. Operating room walls and floors

First, the group collected photo references which later helped the artists compare the results between real life and 3D models, both regarding the model and the textures. A few examples of reference pictures taken by the group can be seen in Figure 3.

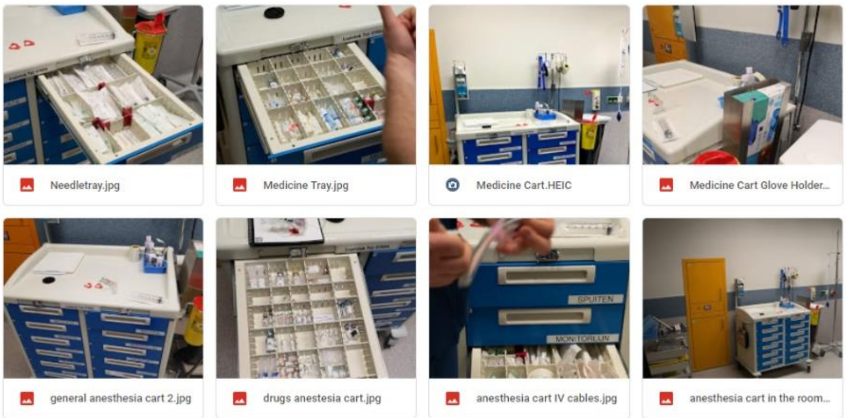
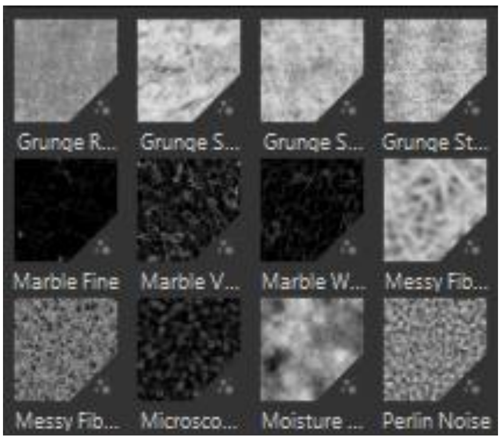


Fig. 3 – *Example of reference pictures taken during the LUMC visit*

The first models created were the walls and the floor of the operating room. To easily adapt the room size, a 3x3 meters plane was created and used. The plane can be tiled as many times as needed to make the room wider or longer.
Using Substance Painter, multiple iterations of the pattern were made in order to get as close as possible to the original.
Figures 4 to 9 showcase the process of creating the darker pattern of the wall texture.
First, multiple noise textures were tested to find the one that closely resembled the pattern seen on the wall. Figure 4 displays examples of procedural noise textures which were tested. The noise texture chosen in the end was “Cells” (Voronoi / Delaunay procedural texture method) because the pattern is similar to the one seen on the walls of the operating room. In addition to that, the different cell colors can be filled based on the colors picked from the reference pictures.



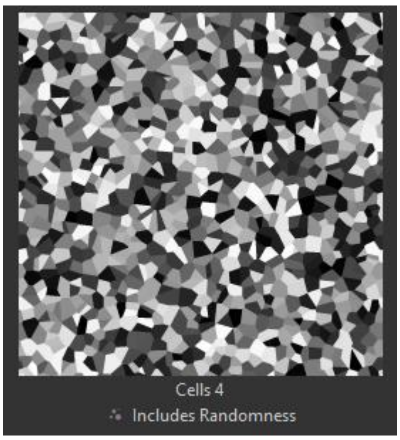
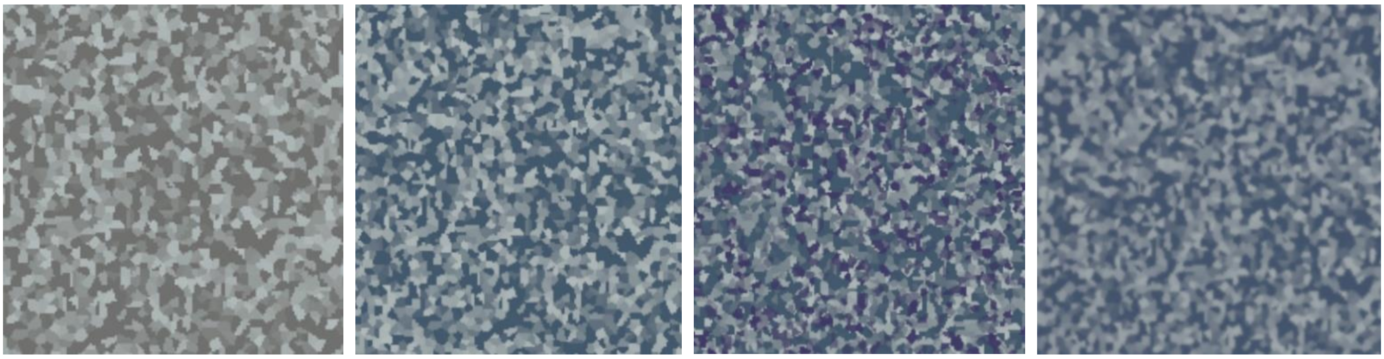


Fig. 4, 5 – *Example of procedural noise textures (Left) and chosen noise texture (Right)*

Figures 6 to 9 show the process of creating the final (dark) pattern of the wall, using the chosen procedural noise (Cells).



1.Procedural Cells texture 2.Base color added to texture 3.Secondary color added 4.Blur applied

Fig. 6-9 – *Steps taken to create the final texture.*

The same process was applied in the texturing of the lighter part of the wall, the only difference being that the colors were changed accordingly. The lighter part was also used to create the floor texture, as the bottom part of the wall seamlessly blends with the floor (pictured in Figure 10).

Fig. 10-12 – *Reference photographs taken in the operating room (Left) and final wall texture (Right)*

Regarding the texture quality, multiple texture sizes were analyzed and tested in order to find a balance between realism and optimization. In order to observe the differences, a set of three texture sizes were rendered and baked.

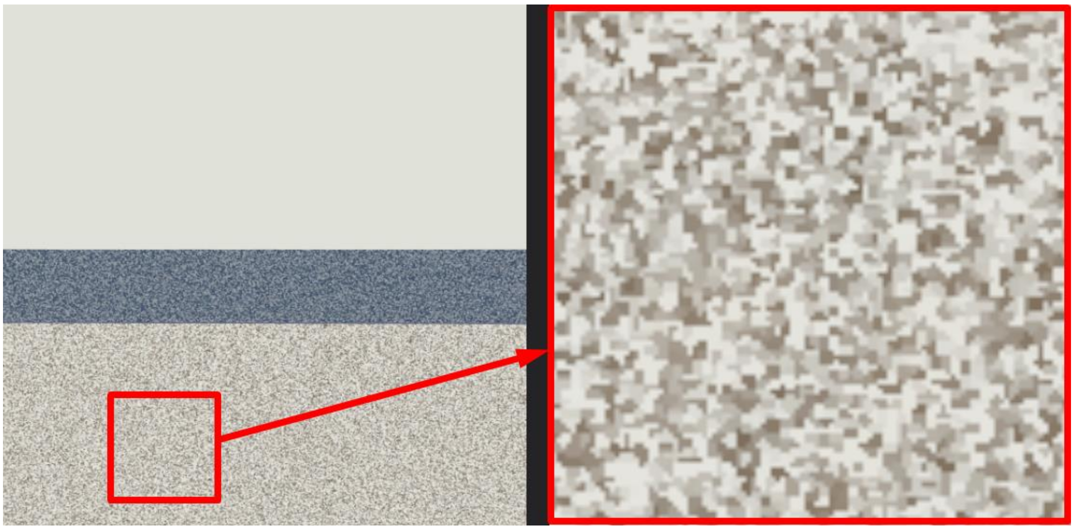
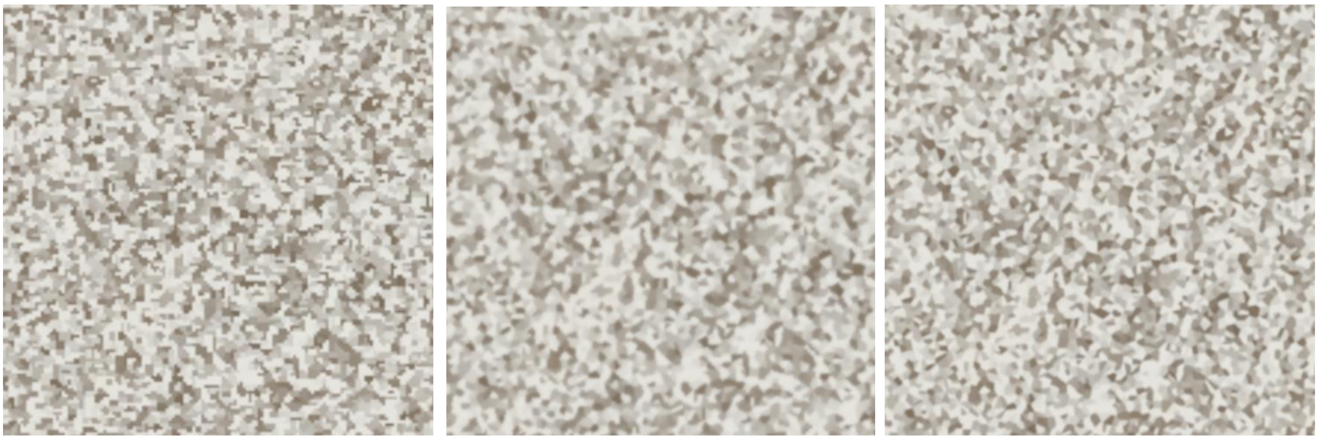


Fig. 13 – *Wall texture quality of 1024 x 1024.*

Figure 13 shows a close view of the 1024 x 1024 texture. This texture was the most optimized, however the details were of low quality and noticeable, and it did not reciprocate the original look of the wall, therefore, it was not used.
Figures 14 to 16 show a comparison between the other texture sizes, using the sample from figure 13.



1024 x 1024 | 2048 x 2048 | 4096 x 4096

Fig. 14-16 – *Comparison between different texture sizes*

The differences between the 2048 and 4096 textures are subtle, however, in terms of optimization, 4096 is less optimized due to being 4 times bigger than the 2048 texture.
In consultation with the client, the preferred option would be the 2048 texture, because of the balanced level of detail and blur, which closely resembles the look of the original room. As a result, the 2048 texture proved to be an optimal choice between realism and optimization.

9.2. Anesthesia machine

The anesthesia machine is one of the high priority assets which went through multiple iterations. At the beginning of the project an artist from the IMT&S group created a simple low-poly model of the anesthesia machine which was used as a placeholder in the VR scene. Figure 17 showcases the placeholder machine initially used in the scene.

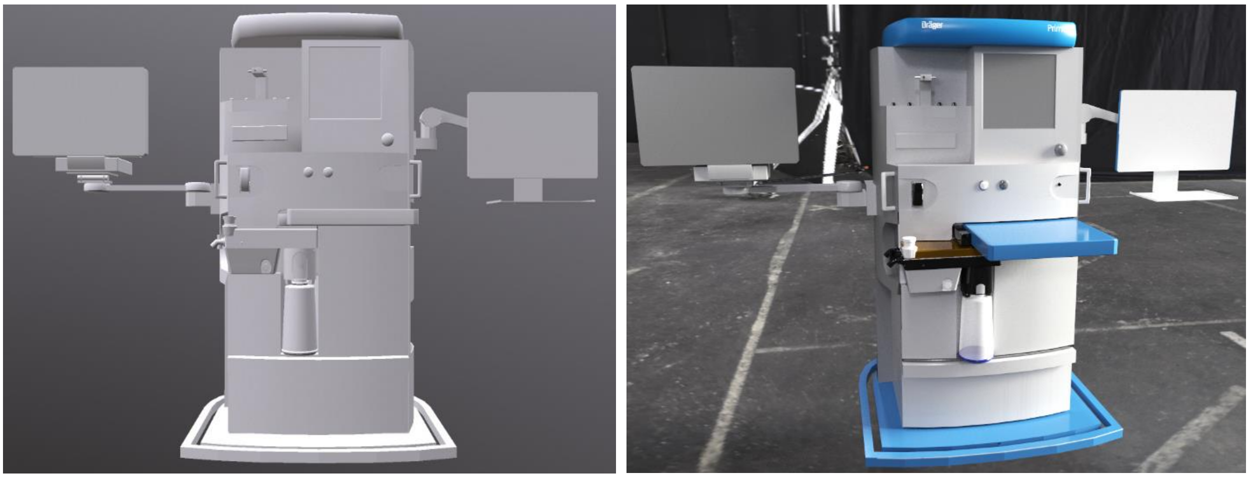


Fig. 17 – Anesthesia machine placeholder (left) and initial textures applied to it (right).

After discussing with the client, their feedback indicated that the machine required modifications and updates so it would look more realistic and so that it can fit the VR training simulation. The placeholder had a few shortcomings, which included the following observations:

- The screen on the left side of the machine did not replicate the original screen used for displaying vitals.
- The shape of the buttons was not clear and similar to the original.
- The arms holding the monitors are not shaped like the real counterparts, thus making the machine too wide and unrealistic.
- The absorber's shape is lacking important details (holder, plug, etc.)
- Missing hardware used for the machine.

Therefore, in a later consultation with the client, the following changes to the placeholder were agreed on:

- The shape of the vitals screen (on the left side of the machine) has been updated
- Overall improvements in level of detail of various parts of the model
- Added missing components and fixed the shape of some parts of the machine
- Added cables and extra hardware (keyboard and mouse)
- Updated the flexible arms which support the monitors

Figure 18 shows a frontal and rear overview of the differences between the placeholder and the updated model of the machine. Overall, the machine looks more realistic, it is more compact, and the added details enhance the general look of the machine.

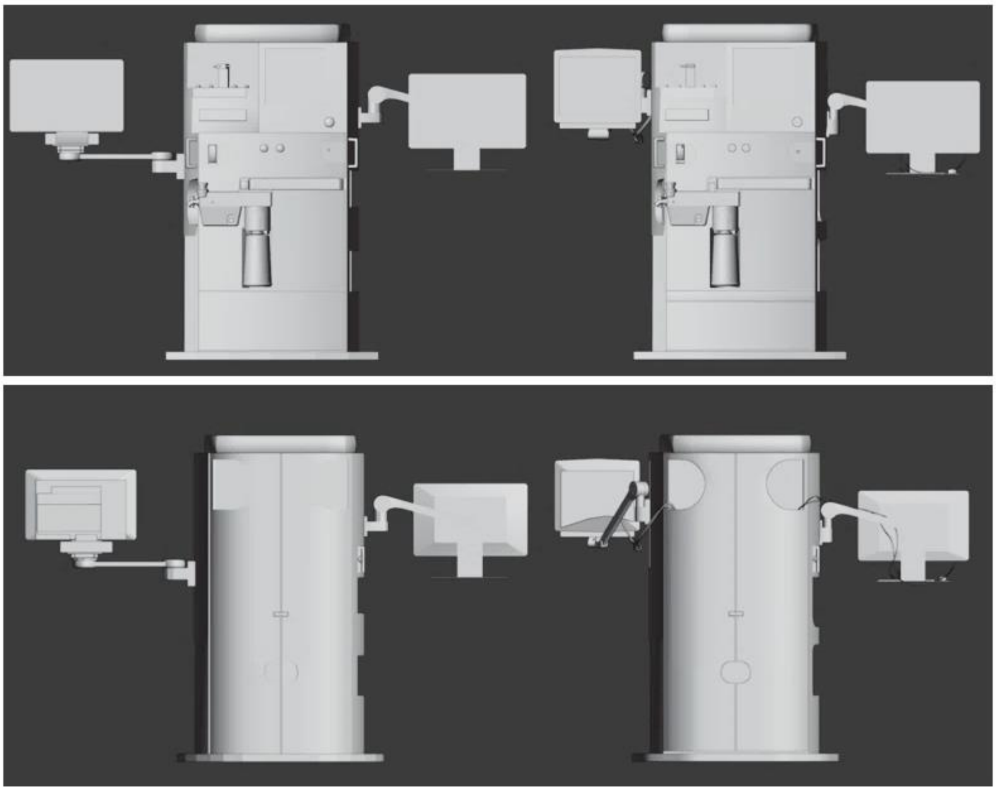


Fig. 18 – *Comparison between the placeholder machine (top and bottom left) and updated model of the machine (top and bottom right)*

A few up-close examples of changes made to the old anesthesia machine can be seen in figures 19 and 20, displaying comparisons between the placeholder and the final model.

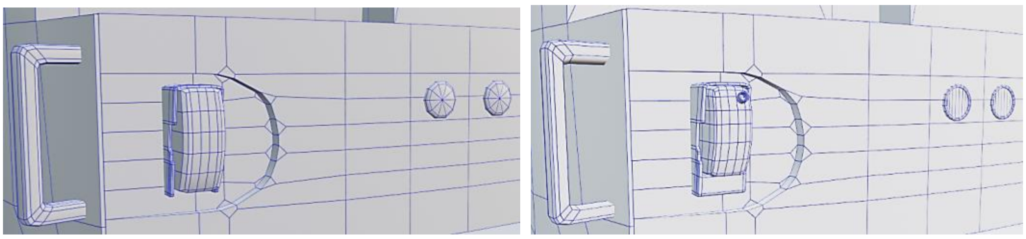


Fig. 19 – *Changes made to the Draeger WaterLock Filter and oxygen meter buttons. The updated model (right) consists of a new holder for the filter, along with a plug, and corrected button shapes.*

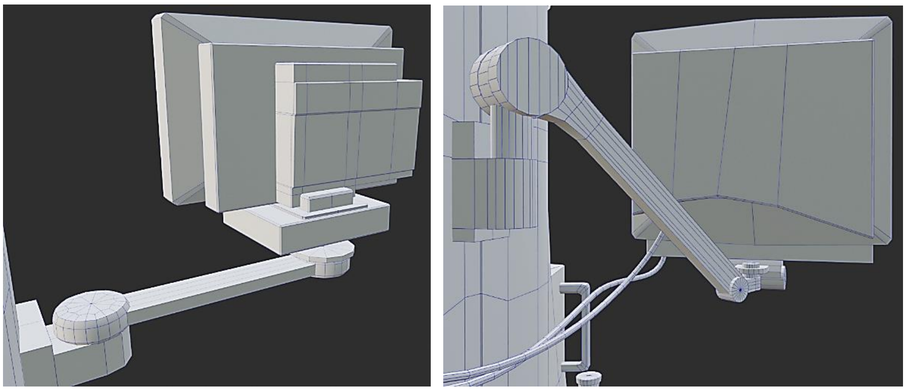


Fig. 20 – *Changes made to the vitals monitor and support arm. The updated models (right) represent an improved arm support, correct screen shape, and added cables.*

Regarding the anesthesia machine textures, the client has indicated that a higher quality is preffered, so that it feels as realistic as possible when interacting with it in the VR simulation. Therefore, after the model was finished, textures were created in Substance Painter, following the reference images taken at LUMC. The final textures do not include the screens of the monitors and the machine because an artist from the IMT&S group is creating an interactive UI which will be placed over the screens in the scene. In order to display the correct logos and text on buttons, parts and monitors, alpha textures (Figure 21) were created to be used as brushes which can be stamped onto the models.
Figure 22 shows a few examples of parts where the alphas were painted.

Fig. 21, 22 – *Examples of a few alphas created (left). Render of the machine displaying the alphas used (right).*

The final textures were baked onto the model at the quality of 4096x4096 in order to preserve all the details (such as the absorber texture, the oxygen buttons or machine start-up button). After reviewing the changes with the client, a few tweaks were made to the cables and other parts in the machine.
Figure 24 shows the final look of the machine in the 3D scene.

Fig. 23, 24 – *Reference image taken at LUMC (left). Render of the final textured machine (right).*

9.3. High-quality models

Some models require high-quality textures in order to clearly display the instructions on them, according to the original design, for example the BiS Quatro Sensor, which is placed on the patient’s forehead.

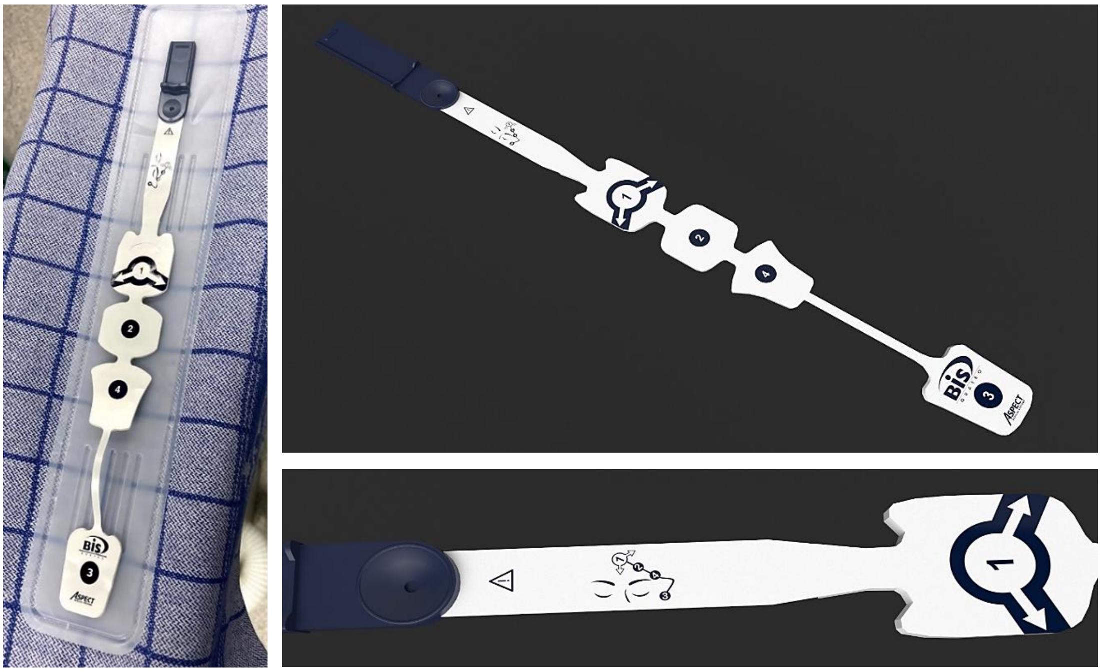


Fig. 25-27 – *Reference picture (left). Renders of the BiS Quatro Sensor model (right).*

Other models, for example the respiration mask, do not require high quality textures due to the fact that they are mostly transparent or have a flat-colored plastic. Therefore, only the shape needed to be closely modeled to the original object.

Fig. 28-30 – *Reference picture (left). Respiration mask render (center) and mask model placed on the patient (right).*

9.4. 3D Avatars

The second highest priority to the environment and assets is the avatar used by the trainees, in order to tell each participant apart. Whether the trainee is a nurse or a surgeon, the avatar needs to display their proper model wearing the correct attire (i.e., sterile, and non-sterile) To help with the production of those avatars, the client provided the group with a reference document which displays what different roles wear during a surgery.

After discussing about the document with the client, I collaborated with one of the 3D artists from the IMT&S group to create a series of prototypes for the trainee avatars.
In order to properly communicate the prototype ideas between everyone involved, I also created a concept art of the options that the trainees can choose from when the prototype is play-tested, as seen in Figure 31.

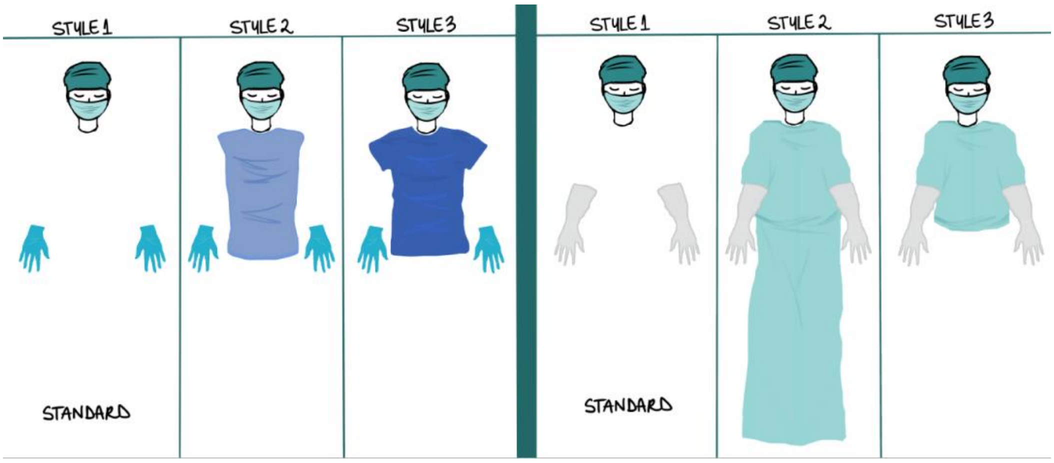


Fig. 31 – *Concept art used for the trainee avatar prototypes*

The model provided by the collaborating artist was used to bake a high-poly model of the shirt on a low-poly version in order to maintain an optimized model with the details and creases of the high-poly model. This baking process was done using Substance Painter, after which the model was textured by applying the corresponding color and fabric material.

Fig. 32 – *Low-poly model of the non-sterile shirt (left). High-poly sculpt of the non-sterile shirt (middle). Rendered model of the final non-sterile shirt (right).*

Figures 33 and 34 showcase the remaining avatars which were created through the same process as the non-sterile shirt displayed in Figure 32. The avatars also contain the other parts (head and gloves) which were exclusively created by the artist from the IMT&S group.

Fig. 33 – Render of the final three non-sterile avatar choices.

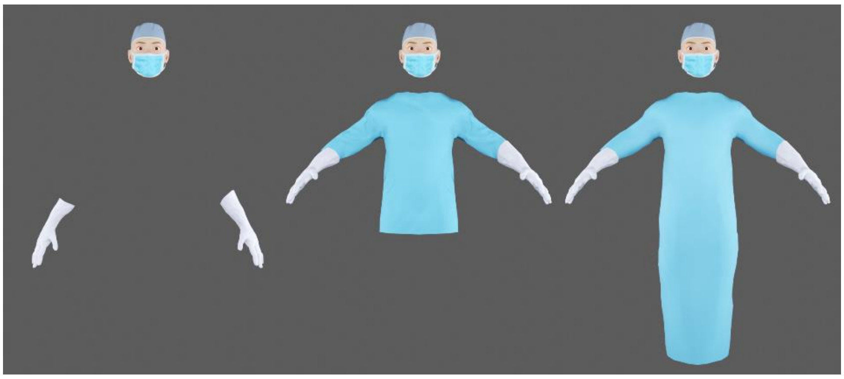


Fig. 34 – Render of the final three sterile avatar choices.

The avatars were then placed in the scene so that the client can view them in VR during the playtest session. Figure 35 shows how they look inside the Unity scene.

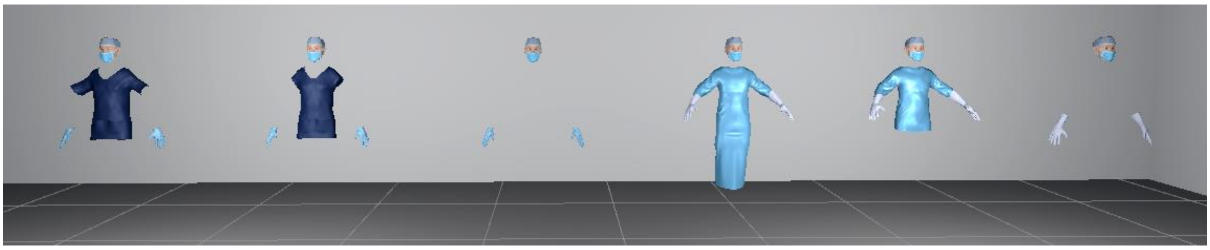


Fig. 35 – All the avatars placed in the Unity scene.

10. VR training simulation demo

After implementing the required assets and functionalities, a build (i.e., application) for the testing session was created. The final demo application contained the following list of requirements:

- Training room
- Multiplayer possibility
- Engineering panel
- Operating room
- Patient with the correct intubation
- Functional anesthesia machine and interactions

After discussing with the client, two playtest sessions were planned and held physically at LUMC. The goal of the playtests was to collect feedback from the participants in order to further improve the demo and prepare it for the next phases of production (see Section 3.1. Client question for more information about the phases of the project).

10.1. First user testing

The first playtest was held on 1st of June 2021. The participants included the clients, Krista Hoek, and Chris Martini, and one anesthesiology resident. Apart from the client, Krista Hoek, the remaining play testers did not have much experience with VR navigation, therefore it was necessary to guide them through the application.
The goal for the first user testing was to gather feedback on the demo application, as such, the participants were given a variety of tasks:

- Testing the training and operating room
- Interacting with the environment
- Analyzing the sound effects
- Interacting with the patient (face mask, surgery, administering a shot)
- Anesthesia machine observation and interaction (observing the vitals monitor, changing oxygen levels, etc.)

The testing session lasted approximately 3 hours, and each participant had just enough time to test the demo thoroughly, ask questions and offer feedback.
Sadly, there were a few issues regarding the internet connection and firewall. The computers provided by LUMC were locking any file download, therefore it was impossible to test the application on them. We did anticipate that similar problems would arise, as such, we also brought a laptop which was suited to run the VR application, so that the client could still test the demo.
Another problem which could not be controlled by either party was that the specific VR headsets ordered by LUMC (Pico Neo 2) did not arrive on time to be used for the playtest. As such, we had to bring a headset which lacked the performance and quality of the expected headsets ordered by the client. To be more precise, the headset brought by us (Oculus Rift) required a wired connection and static sensors which limited the rotation in real-life, as well as the space available for movement (Figure 36). That resulted in us having to often correct the tester’s position in real-life for the VR interactions to work properly.

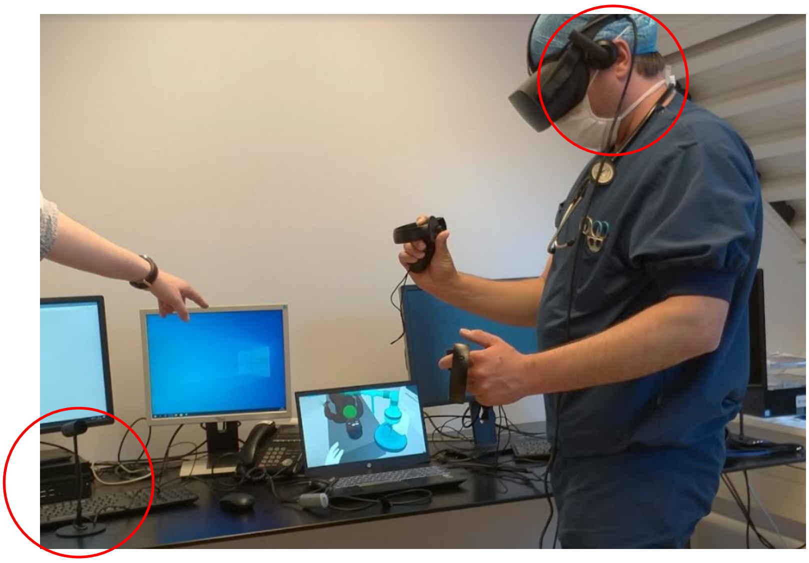


Fig. 36 – Play tester interacting with the patient and facemask.
Highlighted elements represent the sensor and the wired connection of the headset we brought.

In comparison, the headsets ordered by the client (Pico Neo 2) would have been wireless and more flexible in terms of the rotation and movement around the room, due to not requiring any sensors because they are already built in the headset.

10.2. Changes

Regarding the feedback, we asked multiple questions during the playtest about the VR experience, the environment, the patient, and the surgical field. Generally, the reactions indicated that the testers were satisfied with the interactions and details in the scenes.
We then sent a post-test questionnaire to all the participants in order to analyze the feedback of more specific aspects of the demo.
A summary of the replies indicated the following suggestions:

- The patient looked generally realistic (accurate size, features etc.), however, the surgical drapes and BiS sticker were missing, and there were no surgeons
- The avatar choice related to the non-sterile version (see Figure 33) was the sleeved model
- The avatar choice related to the sterile version (see Figure 34) was the full-body model
- The anesthesia machine looked realistic enough, however it was missing the anesthesia vaporizer and tubing to the patient
- The interactions with the anesthesia machine were not similar to real life (adjusting values by pressing on the touchscreen versus tweaking with the rotating button)
- The vitals graphs were clear and understandable
- Transitions between rooms (OR, training, hallway) were understandable
- The engineering panel felt responsive enough

For a detailed overview of the responses, see Appendix B.

Based on the collected feedback, we assigned new tasks and improved the demo further for the next test session. The tasks assigned to me involved creating the anesthetic vaporizer, the surgical drapes, applying the BiS sticker to the patient's head and posing the sterile avatars. In addition to that, I have worked on improving the lighting inside the rooms: models of the neon lamps were created, and the lights were baked to make the environment look as realistic as possible. Figure 37 shows the comparison between the old lighting and the new lighting inside the operating room.

Fig. 37 – Screenshots of the lighting in the room before (left) and updated lighting (right).

The BiS sticker model was already created, as seen in Section 9.3, Figures 26-27, however, it was not yet placed on the patient's forehead and connected to the anesthesia machine.

Fig. 38 – Renders of the patient having the BiS sticker placed on their forehead.

Creating the patient drapes was one of the most pleasant tasks. The process involved a lot of trial and error in order to get the correct stiffness of the fabric and positioning over the patient because it required simulating the cloth onto the surface multiple times.
The textures for the drapes were created in Substance Painter once again, and the colors applied were closely matched to a real-life surgical field.

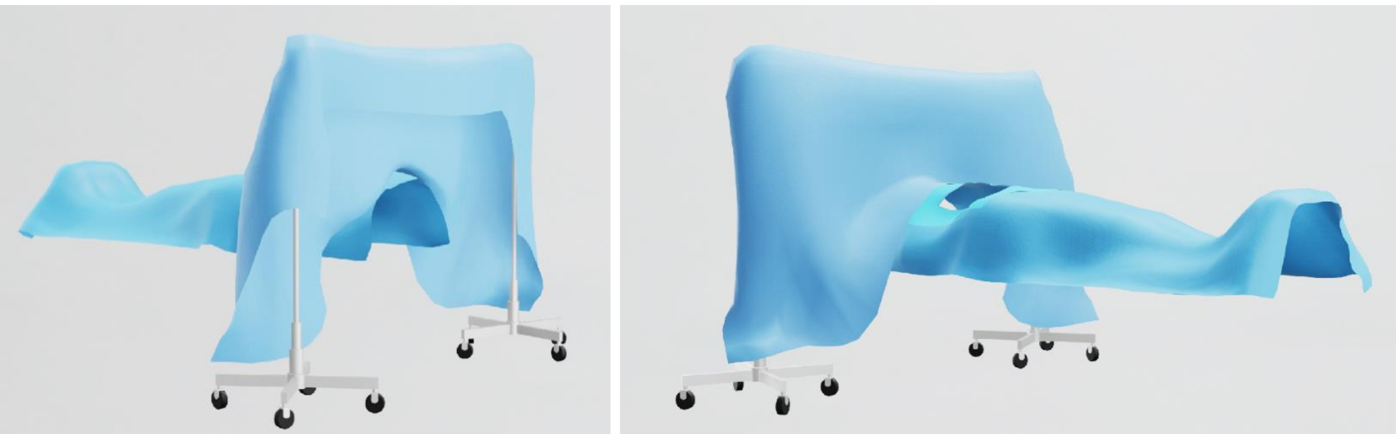


Fig. 39 – *Renders of the patient drapes held by supports.*

The specific vaporizer model used at LUMC was quite difficult to find online in terms of references because there were a lot of different models of the same vaporizer, thus, the only accurate references were the pictures taken by the group while visiting LUMC.
This was a challenge because realism was an important factor in terms of replicating the operating room environment and objects.

Fig. 40 – *Reference picture (left). Render of the Draeger Vaporizer (right).*

Another important task was posing the sterile avatars. In order to do that, I created a simple rig (i.e., skeleton) for the character and posed the bones of the arms and hands to simulate a surgeon working on the patient. To improve realism, I also modeled a scalpel and placed it in the sterile avatar's hand, which can be closely seen in Figure 41, center.

Fig. 41 – Posed rig of the avatar (left). Renders of the final pose (center and right).

10.3. Final testing

The final testing session took place on 9th of June 2021, and the number and diversity of the participants' roles brought valuable feedback for the demo.
The goal for this testing session was to collect feedback which would allow the group to make the necessary and critical tweaks for the demo, as well as offer insight on what improvements can be made in the next production phases.
The tasks that the participants had to complete were quite identical to the ones mentioned in Section 10.1., First user test, keeping in mind that multiple aspects changed in terms of interactions with the anesthesia machine, the environment, and the patient.
The testing session lasted approximately 4-5 hours and the participants had the opportunity to not only experience the demo in VR, but also test it with a different VR headset (Oculus Rift S) which was closer in navigation and usability to the VR headset ordered by LUMC (Pico Neo 2).

10.3.1. Group of students

This group had multiple participants who had a good level of experience in using and navigating in VR, however they had less experience with the real-life simulations.
The participants required less guidance and were more perseverant in testing various interactions (e.g., trying different syringes on the patient, listening to the heartbeat).

10.3.2. Group of residents and doctors

This group's play testers had less experience with the use of and navigation in VR, however it seemed that the controls and interactions were intuitive and understandable enough that it quickly became easy to navigate.
The patience and attention to detail allowed the participants in this group to give more feedback on the spot, explaining what changes would be necessary to improve the anesthesia process (e.g., tubing, feedback on button pressed, stickers on the patient's eyes).

10.3.3. Multiple setups

Similar to the first playtest, the internet issues persisted, making it impossible to test the simulation in multiplayer (two or more participants present in the operating room simultaneously). However, it opened the opportunity to test two different VR headset types – the headset used during the first playtest, with the sensors and limited movement and rotation (Oculus Rift), and a headset with built-in sensors, which allowed 360-degree rotation and a larger movement area (Oculus Rift S). The latter provided the opportunity to experience a similar usability compared to the headsets that LUMC will use in the future project phases (Pico Neo 2).

To collect particular feedback on the prototype, a feedback form was mailed to each participant. The feedback received pointed out tweaks which were critical in order to wrap up the development of the prototype, however, there were certain comments which will be used as an orientation for the production of the next phase.

A summary of the feedback collected after the final testing session indicated the following:

- The environment, patient and assets closely match reality, averaging on a score of 9 out of 10
- The surgical field required more details so that it looks more dynamic (such as adding a spreader)
- The manipulation of the anesthesia machine obtained an average score of 6
- The OR felt too large, or perhaps too empty, requiring more people or assets present in the room
- The transitions between rooms were clear and understandable
- There is a high percentage of participants that think VR simulations could be a complementary training module to the manikin simulator sessions
- A large majority of the play testers would like to continue participating in training simulations

For a detailed overview of the responses, see Appendix C.

11. Discussion

The project has gone through multiple changes, and the feedback provided through every sprint helped the product develop towards the client's vision.
Unfortunately, the obstacles which showed up during the testing sessions, such as the firewall blocking multiplayer interactions and downloading the application, or the delayed delivery of the headsets, set back the true experience of the demo we created.
In retrospective, an earlier planning and establishing of which headset needed to be bought and testing the internet connection with an external computer would have prevented these issues, or perhaps would have offered more time to find a solution around them.

Due to the limited time, there were a few tasks which could not be completed or polished. On one hand, multiple 'filler' assets (such as chairs, syringe carts, air pumps, information boards, etc.) could not be created, thus making the environment feel emptier, as seen in some suggestions from the final test session. On the other hand, due to the lack of medical experience, the group had to spend a long amount of time at the beginning of the project researching procedures, correct naming of each component, the meaning of each value seen on the anesthesia machine's screen, and so on.
As a result, the number of interactions with the machine and patient were limited, because they required polishing and feedback from the client to make sure they were accurate, before continuing with another feature.

Despite the problems encountered, I consider that the project was a success. We managed to deliver a working demo which has a set of clear interactions which can be performed and the feedback from the final testing session further confirmed that VR simulations could successfully become a complementary training module for anesthesiology residents.

12. Conclusion

Using VR simulations as a training tool for anesthesiology residents is a challenging, yet innovative concept which I had the opportunity to explore and develop on during the semester. I have researched about different levels of realism and their impact on training, and I have created multiple prototypes in order to analyze the results in terms of performance.
Regarding the project's process, initially, the expectations of the client about the first production phase were overwhelming, given the limited time. Therefore, it was important to establish clear limits and goals in order to ensure that a working demo would be delivered - from the training scenario choice to the interactions with the patient, and the environment. The next important aspect was the level of realism of every asset created. I have worked closely with the group and the client, ensuring that every model fits their requirements, and that realism can be maintained to every single detail, not only on models and textures, but also on the general look and feel of the environment. The lighting, transitions between the scenes, and positioning of the models around the scenes all take part in guaranteeing that visual realism is replicated according to every reference photograph we have taken.
As indicated before, a higher level of visual realism in the simulations guarantees a good understanding of the environment and information assimilation, thus, resulting in better trained individuals.
Based on the feedback received throughout the project and especially during the final playtests, I can conclude that visual realism in VR simulations can have an impact on the training of healthcare workers. In addition to that, it presents a high potential for further development in the medical field, both for training and education.

13. Recommendations

Due to the project being in the prototyping phase, there are countless recommendations to be given. Among the most important there is the aspect of 3D modeling complex medical machinery. It is time-consuming because of the reduced number of online references and complexity of the machine, thus being costly for the client both financially and timewise, which could have been spent creating important interactions for multiple scenarios or polishing the product.

Secondly, considering the possible growth of the project, and thus, addition of assets into the scenes, the application might require an even more powerful computer. Additionally, using a different VR headset needs to be tested with the application in order to observe the performance. Therefore, it is important to keep track of the optimization of the assets which will be introduced in the scene and any other changes and additions that will be made.

Last but not least, when holding playtests, it is important that the connection will not interfere with the multiplayer aspect, as well as with downloading the application on the device.
While wi-fi connection may allow bypassing the firewall protection, it is unstable and can affect the performance and cause lag during multiplayer sessions.

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Appendix

Appendix A – Table 1

Table 1. Advantages and disadvantages of training various medical groups using VR

Disadvantages	Advantages
The high cost of the simulators	Decrease in the frequency of training and the ease of training using VR (22-28)
The long nature of some studies in the field of virtual reality	Decrease in the time of surgery in the real environment (23,29,30)
The high cost of these studies (high cost of monitors, programming, implementation environment, participants, etc.)	Positive psychological effect on learners (23)
It can never replace the real environment training	Increase in accuracy and accuracy of trainers and reduction of errors (21)
Its implementation requires identification of the effective factors and conditions of that society	Improving the teamwork in the medical team (31)
Additional training using VR without supervision can cause extra stitching, and lead to damages to tissues, and more	Increase in self-confidence in learners using VR compared to other groups (32,33)
The course of studies is very limited; therefore, further studies and more accurate evaluations are necessary	Decrease of harm to those being treated by people who are trained by VR, decrease in mistakes and more successful surgeries (29,33-35)
Some studies have also pointed to the increase in training time (18-21)	Increase in skills of learners (18,21,24,28,36)
	Better learning of anatomical positions (27)
	Better understanding of the exterior and interior space relationships between the organs (27)
	Valuable approach for Standard and unified education of medical groups (28)
	Increase in the skill of surgeon (21)
	Increase in the safety of the physician and patients (21,33,34)
	Decrease in the costs and increase in the efficiency (18,22,26,37)
	Overall performance improvement (32,35,38)

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Appendix B – Feedback form (First testing session)

PATIENT

1. Does the surgery on the patient feel realistic enough? Does it require more detail?

3 responses

i didnt perform the surgery, so i cant answer this question

For me the mannequin in the corner looked very realistic

Hard to answer since the patient that was lying on the operation table wasn't covered in drapes and I was the only one in te room.

2. Does the muscle structure look as expected of a kidney transplant patient? What changes would improve the model?

3 responses

i didnt perform the surgery, so i cant answer this question

It was fine for me

Yes, the patient looked alright.

3. Is the patient's scale accurate? (Size / Height)

3 responses

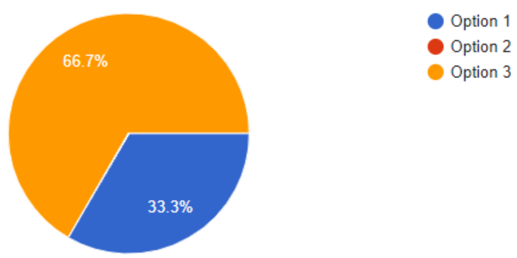
yes

Yes

AVATARS (NURSE & SURGEON)

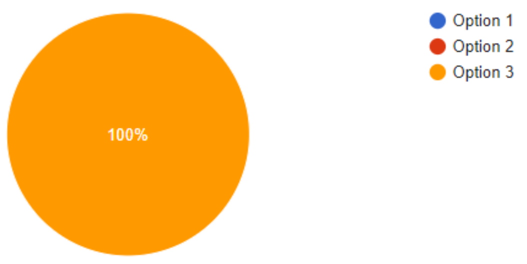
1. Which of six choices was more favorable in regard to the nurse?

3 responses



2. Which of six choices was more favorable in regard to the surgeon?

3 responses



3. Is anything missing or are there any changes required in regard to the avatars?

3 responses

they look good :)

nothing was missing

it's nurse vs surgeon but sterile versus onsterile

ANESTHETIC MACHINE

1. Does the machine feel realistic enough?

3 responses

yes, except for the missing vaporizer

I wasn't able to test the machine

yes

2. Are the interactions with the machine similar to its real-life use?

3 responses

for example the Fi02, we would normally change this value with the round button instead of with the bar

I wasn't able to test the machine

no

3. Are there any missing parts in the machine? (e.g., Anesthetic Vaporizer)

3 responses

only the sevoflurane vaporizer and the tubing from tube to machine are missing, the rest looks very good,

I wasn't able to test the machine

yes we need the vaporiser

4. Are the graphs on the right-side monitor understandable? (The next demo will present the graphs to the correct vitals monitor on the left)

3 responses

I think so

I wasn't able to test the machine

yes

5. Is the anesthetic machine's scale accurate? (Size/Height)

3 responses

i think so

I wasn't able to test the machine

yes

ENVIRONMENT

1. Is the size of the Operating Room appropriate? Does it require changes or additions?

3 responses

It is large, which might not be completely realistic

is fine

yes

2. Is the transition from the starting room to each specific room understandable?

3 responses

yes

yes

3. Does the environment feel realistic enough? (Textures of the walls)

3 responses

yes

4. Does the starting room require more detail (walls / floors / ceiling textures)?

3 responses

no

maybe a formal briefing room with table and chairs?

ENGINEERING PANEL

1. Is the engineer panel easily understandable?

3 responses

yes

I wasn't able to test the engineer panel

2. Is the navigation through the settings clear?

3 responses

yes

I wasn't able to test the engineer panel

3. Is it responsive enough? (e.g., Any lag on button pressed?)

3 responses

yes

I wasn't able to test the engineer panel

no, quite difficult to do cetrain things such as picking up something or clicking on a button

4. Is everything required for the end product inside the engineering panel?

3 responses

i think so

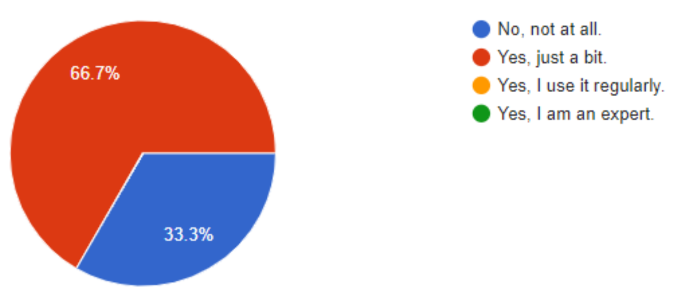
I wasn't able to test the engineer panel

I dont know

Appendix C – Feedback form (Final testing session)

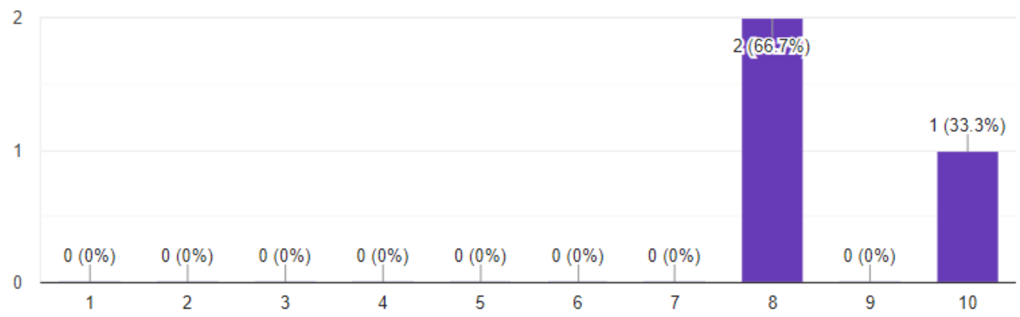
Do you have any experience with VR?

3 responses



Does the patient look realistic enough? Please rate from 1 to 10.

3 responses



Do you have any suggestions concerning the patient?

3 responses

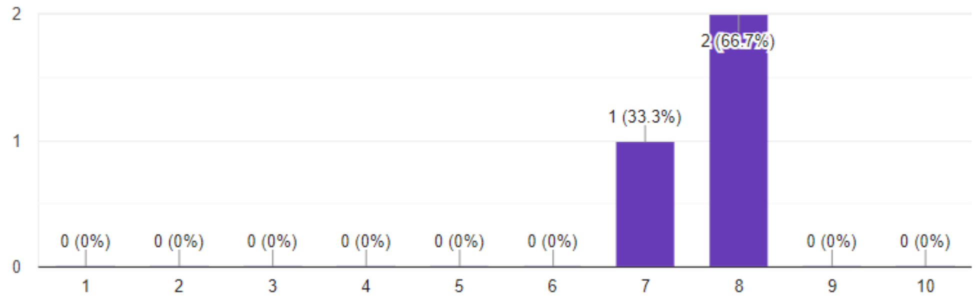
No, not at all

Looks fine

no

Does the surgical field look realistic enough? Please rate from 1 to 10.

3 responses



Do you have any suggestions concerning the surgical field?

3 responses

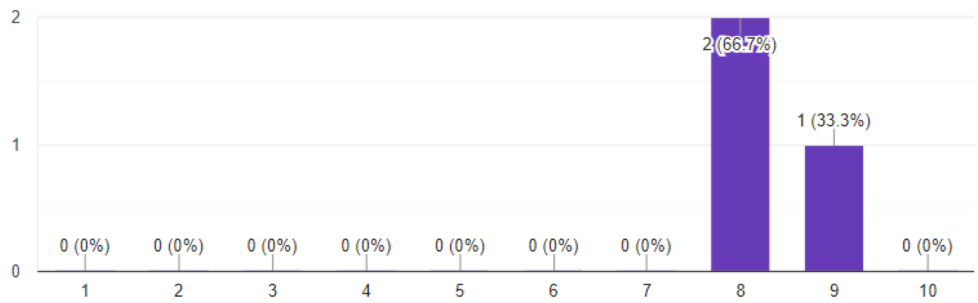
Looks a bit too static to me, maybe a spreader or something like that

Looks fine

no

Does the anesthesia machine feel realistic enough? Please rate from 1 to 10.

3 responses



Do you have any suggestions concerning the anesthesia machine?

3 responses

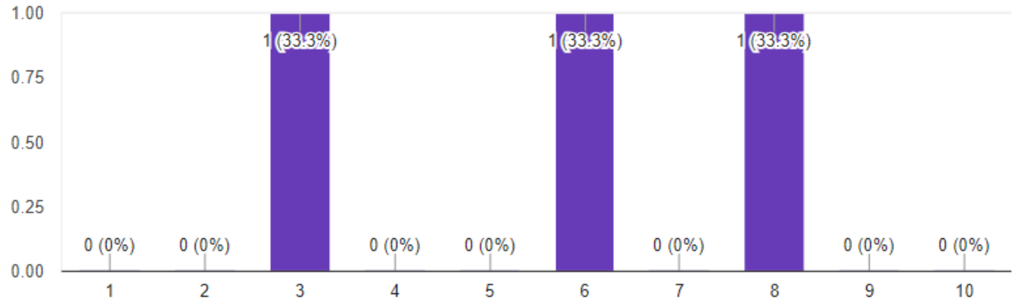
Don't know how they exactly look in real life

Looks very realistic, but does not work yet

i feel the size of the monitor could be a little bigger.

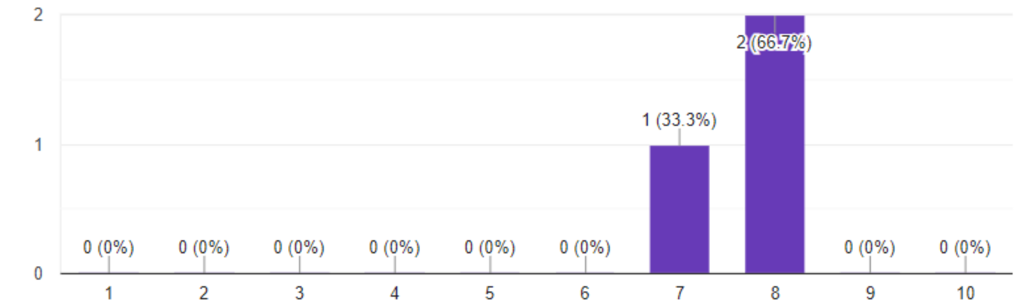
How was the manipulation of the anesthesia machine? Did it work accordingly? Please rate from 1 to 10.

3 responses



Does the OR room/environment look realistic enough? Please rate from 1 to 10.

3 responses



Do you have any suggestions concerning the OR?

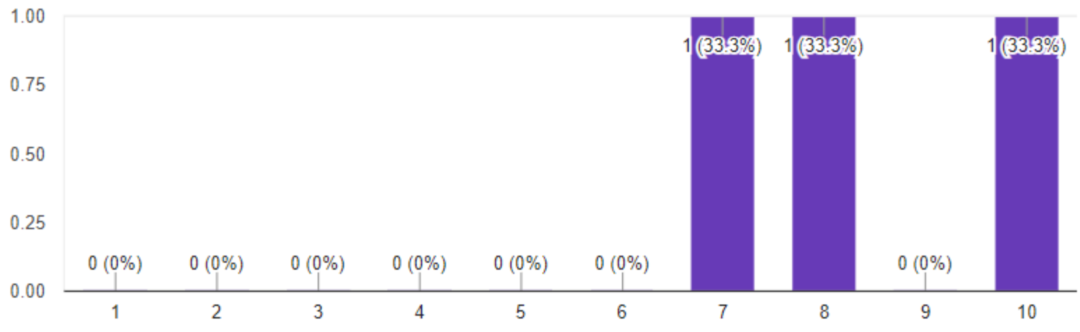
2 responses

In my opinion a little bit too big and very empty

Real OR --> more crowded, more people, more machines/instruments

Does the scale of the VR simulation look accurate? Please rate from 1 to 10.

3 responses



Do you have any suggestions concerning the scaling?

3 responses

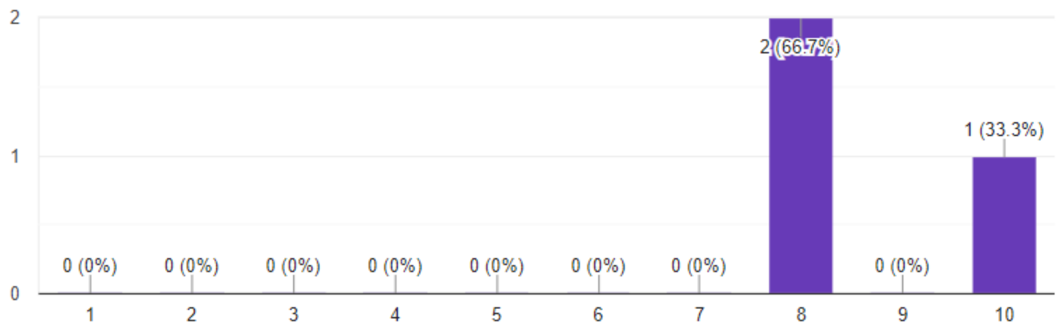
No

Patient files a bit large

The OR room is very big when compared to the patient OR team and patient

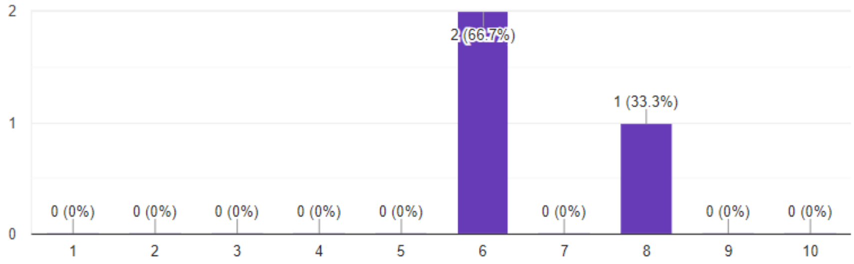
Is the transition from the starting room to each specific room understandable? Please rate from 1 to 10.

3 responses



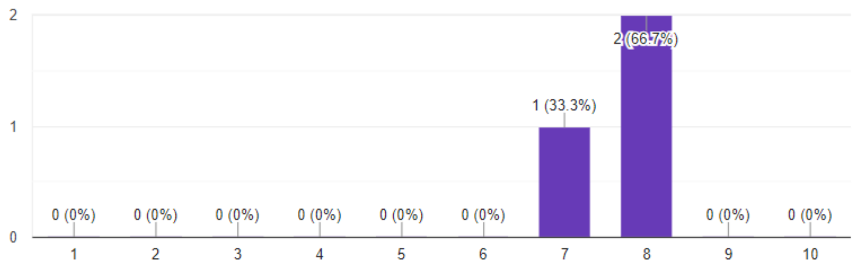
What was your level of comfort during the VR session? Please rate from 1 to 10.

3 responses



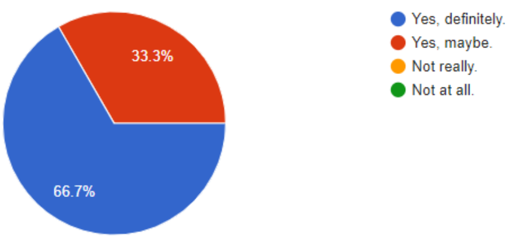
How was your general experience of the application in VR? Please rate from 1 to 10.

3 responses



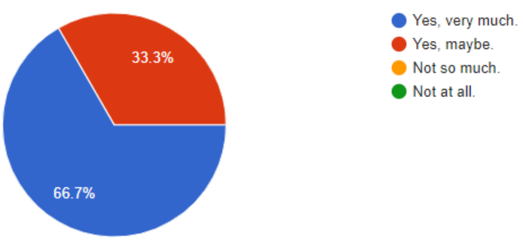
Do you think VR simulations could be a complementary training module to the regular doll-simulator sessions?

3 responses

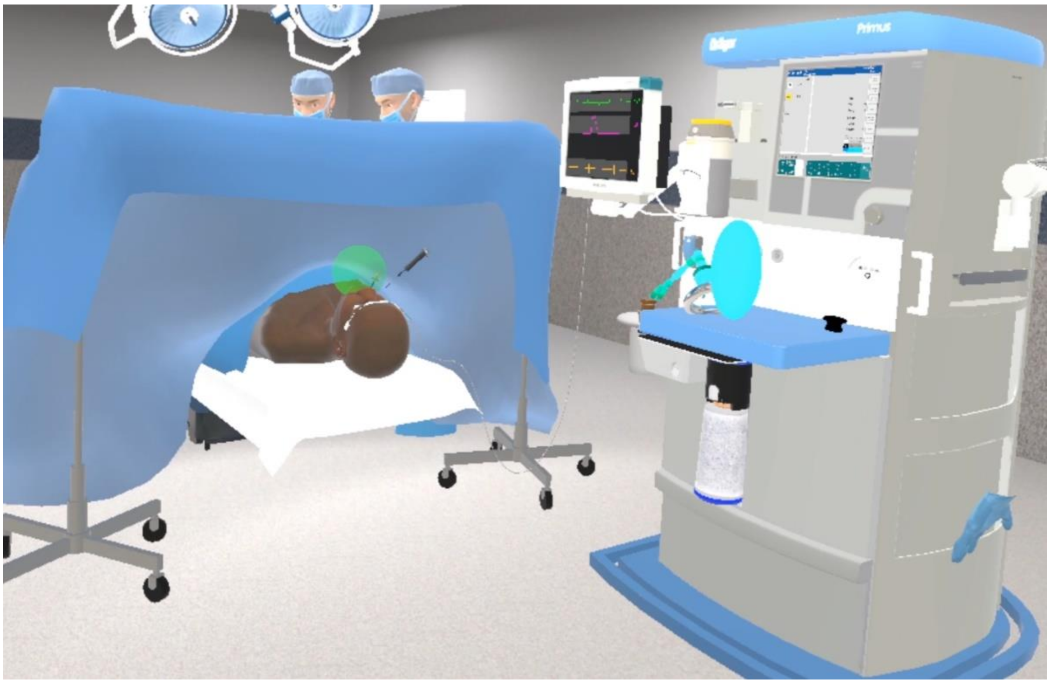


Would you like to simulate a session with VR in the future?

3 responses



Appendix D – Professional products



A demonstrational video recording of the final VR application can be seen at:

https://youtu.be/6kysWhaJauE