

Learning Anatomy with Mixed Reality

Using the Microsoft HoloLens for MRI image
visualization in three-dimensional space.

Master Thesis

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by

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Declaration

I declare that I have developed and written the enclosed Master Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. This work was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

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Place, Date

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Signature

Preface

Being able to walk this rather time consuming educational path was made possible by some people I'd like to highlight in this preface. First and most importantly my family helped me on any occasion. My parents, Dipl-Päd. Andrea and Friedrich Höblinger supported me in any way possible and my girlfriend, Verena Frey, BBSc. helped wherever she could, too. She boosted my courage to tackle this master program and helped me survive long after-work online learning sessions by cooking delicious meals for me. My grandmother, Margarethe Freuinger could never quite imagine what "Digital Healthcare" really was but still was supportive and curious. Unfortunately, Helene and Friedrich Höblinger, my grand parents didn't live long enough to see this but I'm sure they're cheering from above. Thank's to all of you!

Secondly, my boss, Mag. Marie-Luise Schmidt made it possible to attend classes by giving me shifts which allowed me to do so. Because, while this master program was meant for working people, having classes on a friday afternoon didn't really help.

What is now a readable English text, was more like a car accident of English words before Mr. Daniel Stiller, an acquaintance of mine read it.

Thank you, Dr. Helmut Ritschl, MA MSc for introducing me to the master program "Digital Healthcare" in the first place – an introduction to the right topics in the right moment.

Microsoft released the HoloLens a while back. Without their encouragement in the technological, medical, educational and scientific field, the subtitle might as well read "Using the Nintendo VirtualBoy for MRI image visualization in three-dimensional space." – and frankly, it would not be the same.

Lastly, this master thesis would not be what it is without the support of my first advisor Andreas Jakl, MSc and Dipl.-Sporting. Dr. Mario Heller.

Abstract

Introduction

Augmented and Virtual Reality are known to the educational field and the medical field. According to literature, most of the existing use cases involve additional periphery and do not target physiotherapists and occupational therapists.

Scientific Question

Can Mixed Reality be used as an educational tool for learning about anatomical structures and MRI images by physiotherapists and occupational therapists?

Methods

A Mixed Reality application was created which displayed virtual elements of the human hand in reality. Participants were then asked to try out the features of the application before answering a questionnaire based on ISO 9241/10. This is a descriptive study.

Results

The answers to the questions of the inquiry showed, that the prototype available to the participants is suitable for an educational environment but cannot replace MRI images for the purpose of learning anatomical structures because the application was lacking some of the features and possibilities an MRI image would have.

Kurzfassung

Einleitung

In der Lehre und insbesondere im medizinischen Feld sind Virtual Reality und Augmented Reality keine Fremdwörter mehr. Laut der Literatur, kam aber bei bestehenden Anwendungen zusätzliche Peripherie zum Einsatz. Ausserdem standen noch keine PhysiotherapeutInnen und ErgotherapeutInnen im Fokus.

Wissenschaftliche Fragestellung

Kann Mixed Reality als Werkzeug von PhysiotherapeutInnen und ErgotherapeutInnen eingesetzt werden, um anatomische Strukturen und MRT Bilder zu erlernen?

Methoden

Es wurde eine Mixed Reality Applikation geschrieben, die virtuelle Elemente einer menschlichen Hand darstellt. Die TeilnehmerInnen wurden gebeten, die Funktionen der Software auszuprobieren um anschließend einen Fragebogen nach dem ISO 9241/10 Standard auszufüllen. Dies ist eine deskriptive Studie.

Resultate

Die Antworten auf die Befragung zeigten, dass der den TeilnehmerInnen zur Verfügung stehende Prototyp für den Einsatz in der Lehre passend ist. Er kann allerdings keine MRT Bilder zum Zweck des Erlernens anatomischer Strukturen ersetzen, weil der Applikation einige Funktionen fehlten, über die ein MRT Bild verfügt.

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1 Introduction and literature research

Digital Healthcare beautifully combines today's most important fields in a single term. The society as we know it today relies on modern technology in so many aspects as it never did before. Technology nowadays is much more than just scary machines and doing the heavy work in an industrial field. With smartphones, and even before that, everyday technology is now in the palm of our hand. Whether we want to go shopping, do the laundry or drive a car – the technology always assists us in our doing. Technology evolved from a monstrous apparatus used for only exhausting work to a tiny microchip helping us order toilet paper.

1.1 Different types of learners

As the software that will be evaluated by this study targets learners, knowing about different learning styles is important. Categorizing learners into different groups is tried in many different approaches. One of the most popular is David Kolb's model (Kolb, 2015). The 1939 born American educational theorist proposed a model that differentiates between four main groups of learners: accomodator, converger, diverger and assimilator. Each of those groups prefers concrete experience over abstract experimentation (Kolb, 2015) or vice versa or a combination of both. An accomodator prefers practical teaching. The converger applies a learned theory and thereby combines concrete experience over abstract experimentation just like the diverger who needs to discuss topics to learn about them. Finally, the assimilator prefers thinking about a topic.

A Study from 2007 suggests that novice learners prefere active experimentation (Salehi, 2007). Since it is common to teach anatomy first at universities and universities of applied sciences the software was developed in hinsight to this circumstance. Senior students prefere, according to Salehi (2007), abstract conceptualization. Salehi (2007) based his study on Kolb's model (Kolb, 2015). Keeping Selehi's (2007) findings in mind, it becomes clear that the ability to touch

and interact with the model of the human hand addresses junior or novice learners. On the other hand, the ability to walk around the model and discuss what they see especially appeals to senior learners.

Another model describing different types of learners is Neil Fleming's VARK model (Fleming, 2001) based on Not Another Inventory, Rather a Catalyst for Reflection (D. Fleming & Mills, 1992). Mr. Fleming's model is supported by different sensory inputs: visual, auditory, read and write and kinesthetic. The program written for this master thesis makes use of three of the four possibilities. The probands can see the model of a hand, read the name of the element of the hand they're looking at and touch the hand. Touching the hand increases and decreases the opacity of the element that was touched. It was stated that by understanding and integrating the VARK model into teaching, one can stimulate students (Othman & Amiruddin, 2010). Marcy (2001) concluded that the majority of the participants of her study fell into the multimodal category of the VARK model meaning that they are not only a visual, auditory, read/write or kinesthetic type of learner, but some combination of those four.

Given the results from the research on learning styles, the software written for this study was designed accordingly. Not only does it address Fleming's types, but it also allows a concrete experience and an abstract experimentation. The users can interact with the model of the hand and experiment with the different elements by changing their opacity. An accommodator can touch the virtual hand. The converger can apply the anatomic theory to the model. A diverger may be able to discuss the different elements of the hand with an observer in the same room. And finally, the assimilator can interact with the model too and then reflect on their findings by discussing them with other students or comparing them with classical methods of learning like a book. Miller et al. (2001) stated in their research report that the diversity of learners is often forgotten about. A mistake which was tried to be avoided in this study.

1.2 Mixed Reality used for learning

With Virtual Reality on the rise, the need for scientific proof that Virtual Reality can in fact improve the learning behaviour of students increased. Several studies attempted to evaluate the effect of Virtual Reality on learning behaviours before. Some of the authors of the researched literature are sceptical about the positive impact of Virtual Reality. Richardson (2011) stated, that a Virtual Reality simulation of the human heart could imply that the organ has a predictable behaviour and therefor might lead to the misconception, that organs behave like

machines. A misconception strongly discouraged by the principles of biology, according to Richardson (2011).

Realism can make a vast improvement to Virtual Reality learning applications. A study, evaluating the usefulness of simulator for prostate biopsy by Fiard et al. (2013), concluded, that realism matters. Senior urologists stated that the feedback given by the simulator did not meet their expectations (Fiard et al., 2013) to realism. Still, Virtual Reality training can improve the performance of students. Studies examining the learning curve of students training with a Virtual Reality simulator showed that these simulators could bring an improvement to the learning curve (Selvander & Åsman, 2012; Sheth, Fader, Tergas, Kushnir, & Green, 2014). This was hinted by the narrowing of the performance gap in the study by Sheth et al. (2014).

1.2.1 Virtual Reality in literature

Virtual Reality is, according to Sánchez et al. (2000) a metamorphical parallel to our real world and can therefore impose some limitations on learning applications. He states that a learner using a Virtual Reality device can get carried off to another world but also mentions, that the real environment, the place where the learning takes place, must be taken into account. (Sánchez et al., 2000). This proves to be difficult with devices like the HTC Vive or the Oculus Rift, since those devices immerse the user into another world, far away from the real environment, far away from where the learning takes place. In order to bypass these limitations, one has to look for a solution that takes the real environment into account. The Microsoft HoloLens could be such a solution. That's why it was the device of choice for this study.

1.2.2 Mixed Reality in literature

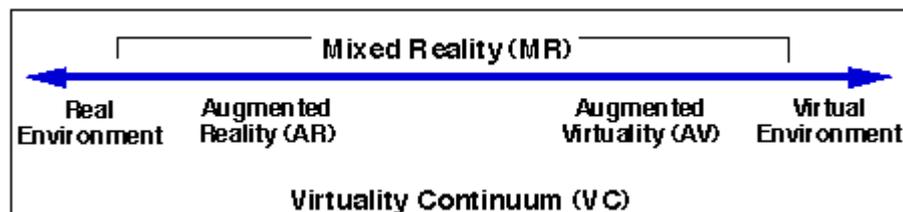


Figure 1 *Simplified representation of a "virtuality continuum"* (Milgram & Kishino, 1994)

Mixed Reality was defined by Yusoff et al. (2010) as a system that combines real and virtual. It creates an immersive environment which is less likely to draw the users into another world, encapsulated and separated from the real world. Other than Virtual Reality, Mixed Reality is not a completely synthetic world (Milgram &

Kishino, 1994). Figure 1 clearly shows that Mixed Reality has a large span from the real environment to a virtual environment. Both extremes are, however, not Mixed Reality. Mixed Reality devices must not always be head mounted, as Milgram et al. (1994) point out. Stationary monitors overlaying images over the real environment can also be Mixed Reality devices. However, it is worth pointing out that this study is from 1994 and while many things are still valid, the world of Virtual Reality and Mixed Reality has evolved since then.

1.2.3 Mixed Reality environment

As written before, it is important that the environment and all the objects within this environment are as realistic as possible. Otherwise, the user would not be allowed to have an immersive experience. Parallely, the objects in a Mixed Reality environment have to have attributes that allow the real environment to still be present, because the setting must be taken into account (Sánchez et al., 2000). These attributes include size and color. An object which is larger than the room, where the learning takes place, can not only reduce the usability of the application but also the effect on the learning curve of the learner. Speaking of color, models should still be realistic (Yusoff et al., 2010). They state that printed elements lose the appeal of their three-dimensional appearance. Therefore, Mixed Reality has an advantage over classical methods like a book.

Holding the life-size model of a real hand provides some extremely useful features. First of all, the model enables the holder to acknowledge the size of the elements of the hand and all the features of the bones, given the user is holding the skeletal model of a hand. By touching the model, the user can feel the features and the texture of the bones, he receives somatosensory feedback. Also, he can – if the model takes that into account – feel the weight of what he is holding. The user can hear the sound of their fingers sliding across the surface of the model, too. In Mixed Reality, and even to a larger extent in Virtual Reality, this somatosensory feedback gets lost by the nature of the devices used. However, somatosensory feedback would be a very important addition to the Mixed Reality environment (Fiard et al., 2013; Yusoff et al., 2010) although Norman et al. (2012) noted that the difference between low-fidelity and high-fidelity simulators is only a minor, that did not match with the feedback of their participants of Fiard et al. (2013) who stated that the lack of realism had a negative influence.

1.2.4 Features of Mixed Reality

The features of Mixed Reality are very similar to the ones of Virtual Reality. It is important to know about these features in order to design the Mixed Reality

environment accordingly and to immerse to user as much as possible while not losing the relation to the real environment, the place where the learner is executing the application. One of the mayor points Sánchez (2000) made is revolving around navigation. Since the user of a Mixed Reality device is not immobile, but able to walk around in the real environment, it must be taken care of this circumstance while designing the software for the learner. There are different modes of navigation in a Virtual Reality environment. Some of which are flying and walking (Sánchez et al., 2000). It was found that walking around freely in a Virtual Reality environment improves the ability to navigate and fulfil tasks of the subjects of the study (Riecke et al., 2010). In their paper, Riecke et al. (2010) also pointed out that the ability to navigate in such an environment is sometimes notably worse than in the real environment. However, a high visual realism indeed improves the participants performance. A finding that matches with the findings of Yusoff et al. (2010).

In their paper, Sánchez et al. (2000) also noted the importance of scale. This feature enables the designer of a software for Virtual Reality to bring the learner closer to the object they are learning about. Being able to change the viewpoint at will is maybe one of the most used selling points of Virtual Reality and Mixed Reality devices. Especially when it comes to Mixed Reality, co-operative learning seems to be a feature that could further improve the experience of the learner. It is also a feature of Virtual Reality, according to Sánchez et al. (2000), just like the user-environment interaction and of course, autonomy. Autonomy in Virtual Reality describes the ability to pursue one's own goals.

It was once necessary to have a wide range of different professionals in order to design the environment and the software. Not only were designers needed for designing the virtual world (Sánchez et al., 2000), a team producing software for Virtual Reality also needed engineers to design the sensory interfaces and the devices. Graphic designers would be modelling animations and polygonal figurines. And finally, the programmers would combine all that and create the Virtual Reality experience. Since the study was finished in the year 2000, naturally many things have changed. Six years before the initial release of Unity, the world of Virtual Reality programming involved much more than now, eighteen years later. Virtual Reality has reached mainstream, allowing programmers to use existing devices with existing APIs. Platforms like the Unity asset store reduce the programmers need for a graphic designer in order to create a small prototype or even a larger project. So, while the points made by Sánchez et al. (2000) may not be valid when it comes to designing and creating minor projects or simple prototypes, the whole field of Virtual Reality still involves all the professions mentioned above.

1.3 Status quo

Although Virtual Reality already has been existing for over two decades it still is a very new, exciting technology. Virtual Reality is used in the medical field. Most of the literature (Selvander & Åsman, 2012; Sheth et al., 2014; Wang et al., 2014) quoted above however, describes procedures using not only Virtual Reality glasses or Mixed Reality devices but solutions involving more than only a headset. Those situations rather involved periphery like a controller. By reviewing the literature, one can clearly see, that most of the existing use cases involve periphery or specialized training simulators like the DentSim. Studies evaluating existing technologies do speak of a positive experience (Buchanan, 2004). Another study evaluated the effects of Symbionix LAP Mentor, a training device for laparoscopic surgeries. They concluded that the device did not have any influence on the learning curve but enabled the students to finish surgeries faster (Wang et al., 2014). Another simulator, the EYESi simulator, was used in yet another study. The study showed a rapid improvement in an initial phase (Selvander & Åsman, 2012). A systematic review of twenty-seven relevant studies evaluated the effectiveness of Augmented Reality applications in an educational environment. They concluded, that none of the studies showed evidence that those applications can transport information to the user (Barsom, Graafland, & Schijven, 2016).

All of those studies were settled in the medical field and were split up in three categories: laparoscopic surgery, neurosurgery and echocardiography. All of the studies involved a Virtual Reality or Augmented Reality simulator relying on different kinds of technology. Some simulators were tracking the instruments, while other ones were tracking the user's head. No study was making use of a lightweight solution like a Mixed Reality headset. This sets the methods of this study apart from the studies contained in the systematic review by Barsom et al. (2016). They also explicitly expect the Microsoft HoloLens to propel the new developments in the medical and educational field (Barsom et al., 2016).

1.4 Quo Vadis

Since studies using a Mixed Reality device like the Microsoft HoloLens are rare to find, carrying out such a study can increase the validity of the usage of Mixed Reality devices in an educational field. Only devices specifically developed for certain medical tasks seem available and tested. Using a device capable of running a multitude of applications can bring improvement. Also, the relevance for physiotherapists and occupational therapists and the effect on those two

healthcare professionals is not examined well yet. This study specifically addresses those two professions and seeks to evaluate to benefit for them. Lastly, most of the existing studies found Virtual Reality, Augmented Reality and Mixed Reality to be helpful and useful in an educational setting but none of the studies saw a significant benefit for the users compared to traditional methods. This study tries to prove otherwise.

1.5 Goals

The goal of this study is to evaluate if a Mixed Reality visualisation of MRI imagery is accepted in an educational field and if it can contribute to the understanding of radiologic images of physiotherapists and occupational therapists. The study takes a look at the usability of Mixed Reality applications in an educational setting. The probands will be able to move around the virtual object in a real environment and look at it from any angle. By the end of this study it should be obvious how this new way of learning influences the understanding and the learning behaviour. Another goal of the study is to evaluate the way of presenting different information on screen and the design of UI elements.

1.6 Non-goals

This study does not want to compare different methods of learning and understanding an MRI image. The method of learning about an MRI image as it is proposed by this master thesis stands on its own. It's not a goal whether or not this way of learning is considered good or bad. Also, this study is not aiming for evaluating Mixed Reality in a therapeutical setting. This software will not be used for diagnosis or treatment of a patient and therefore evaluation of the effects of the software in these fields is not a goal either.

1.7 Research question

Can a Mixed Reality application replace MRI images in an educational setting and can this Mixed Reality software please all the needs of physiotherapists and occupational therapists when learning anatomical structures? Furthermore, is the software capable of delivering all the features an MRI image can provide in an educational setting?

2 Development

Generally speaking, the developed software uses a 3D model of a hand, displayed in Mixed Reality. It also shows what elements of the hand you're looking at and allows different kinds of interaction with these elements. The whole process started by acquiring an MRI scan of a hand. The anonymized DICOM dataset was then loaded into 3D Slicer.

2.1 MRI images

Besides computer tomography scans, magnetic resonance imaging is one of the most important and widely used imaging techniques used in the medical field. Instead of using ionizing radiation, an MRI scan uses electromagnetic radiation and magnetic fields (Hashiman, Lisanti, & Bradley, 2010, p. 22). Those two instruments allow the scanner to also calculate the electric field gradient, which helps imaging tissues. Contrary to a computer tomography, an MRI does not use X-ray but makes use of an effect called "nuclear magnetic resonance". Nuclear magnetic resonance makes use of the discovery, that some nuclei rotate around their own axis, much like planets or a wheel. Unfortunately, those rotational axes do not have the same orientation. That's why a magnetic field is needed to align them all in the same direction. The nuclei are now spinning like spinning tops. It is called "precession". An impulse is then applied in order to cause excitation. After this impulse was performed, the nuclei re-align their axes. During this phase, which is called relaxation, two effects become visible. Firstly, the nuclei emit energy. This is called T1 relaxation and causes lighter or darker color depending on the thermal conductivity of the tissue. One can also define the lightness and darkness of tissue on the final image by observing the T2 relaxation. Different tissues behave differently. This difference is used to distinguish between different tissues. More precisely, the time it takes for the nuclei to re-align their axes allows to differentiate tissues.

2.1.1 Image weighting

Based on the preferred method, either T1 or T2 weighted images (Hashiman et al., 2010, pp. 75, 87) result from the MRI scan. By modifying different parameters, the user of the MRI scanner can fine tune the weighting. The time that passes between two high frequency pulses is called repetition time (Hashiman et al., 2010, p. 40). The longer the repetition time the more the image is T1 weighted. The second important parameter that can make the difference between a T1 and a T2 weighted image is called the echo time (Hashiman et al., 2010, p. 181). If the echo time is set to a long period, the image will be T2 weighted. Different combinations of those two parameters are usually pre-set as so-called MRI sequences. DANTE (Bernstein, King, & Zhou, 2004, p. 171) (Delays Alternation with Nutations for tailored excitation), GRASS (Bernstein et al., 2004, p. 584; Hashiman et al., 2010, p. 252) (Gradient Refocused Acquisition in the Steady State) and MPGR (Hashiman et al., 2010, p. 252) (slice-MultiPlexed Gradient Refocused acquisition with steady state) are just some of more widely used MRI sequences available. T1 weighted images are better suited for imaging tissues containing large amounts of fat. On the other hand, T2 weighted images are preferred whenever water-rich structures, like edemas or tumors need to be pictured. The three-dimensional objects used in this study derive from both, a T1 weighted image and a T2 weighted image. While the T2 weighted images allowed a more accurate extraction of three-dimensional models of the tendons, muscles, cartilages and arteries, the bones were extracted from the MRI images that were T1 weighted.

2.1.2 Relevance for physiotherapy

MRI imaging has proven to be very useful for physical therapists (Deyle, 2011), because it allows them to accurately diagnose the patients problems. Therefore, understanding MRI images can be named as one of the most important skills of a physio therapist, especially in a region with a direct access setting. In such regions, patients are allowed to visit a physiotherapist without consulting a doctor first. Unfortunately, Austria is not yet such a region. However, *physioaustria* suggested such a model in the year 2017¹.

¹ <https://www.physioaustria.at/news/direktzugang-zur-physiotherapie-eine-zukunft-ohne-verordnung-oesterreich> (visited 19.02.2018)

2.2 DICOM

The abbreviation DICOM stands for Digital Imaging and Communications in Medicine (Mildenberger, Eichelberg, & Martin, 2002). This standard² is used by hospitals, doctor's offices and manufacturers of medical imaging apparatuses like MRI scanners, endoscopy devices and ultrasonic examination devices. The DICOM standard is widely used across multiple medical fields like radiology, dentistry and pathology. The DICOM standard does not only describe a file format but also defines the means of transmitting medical images by defining a communication protocol. It also includes a look up table to unify the greyscale across different monitors and printers³. The standard was formerly known by the name "ACR-NEMA"(Mildenberger et al., 2002) and was renamed to DICOM in the early nineties. The American College of Radiology and the National Electrical Manufacturers Association agreed on an early version of the standard in 1985.

2.2.1 DICOM file format

A DICOM file is a binary file which definitively connects a patient ID with the images belonging to that certain ID. Therefore, images of different patients cannot be confused. The file consists of a list of arguments and can be read by a variety of different applications such as 3D Slicer or RadiAnt DICOM Viewer⁴. There even exist libraries that allow working with DICOM files, like openDICOM.NET⁵ for the programming language C#. The arguments of DICOM files allow the storage of information, describing the device, the image and the patient in detail. There are fields for the patient's name, the patient's ID, the patient's sex and even for the patient's address among many more. The file can include detailed information, e.g., about the echo time used during the MRI scan. There are over three thousand attributes available to the DICOM file⁶. One of those attributes is the image data. One DICOM file stores only one picture and the accompanying information about the patient, the device, the image and so on. Since an MRI scan results in many images, one for each slice, the image data of an MRI scan comes as a file set. This file set consists of many files. Each of these files contains one slice of the scanned object. However, DICOM files can contain different frames, adding the possibility to combine different images into one

² <https://www.dicomstandard.org/> (visited 19.02.2018)

³ http://dicom.nema.org/Dicom/2011/11_14pu.pdf (visited 19.02.2018)

⁴ <https://www.radiantviewer.com/> (visited 19.02.2018)

⁵ <http://opendicom.sourceforge.net/> (visited 19.02.2018)

⁶ <https://sno.phy.queensu.ca/~phil/exiftool/TagNames/DICOM.html> (visited 19.02.2018)

DICOM file. This is useful for imaging techniques that are multi-dimensional images.

The MRI images used in this study derive from the diagnosis and treatment of a patient which was not performed as part of this study. The resulting images were then transferred voluntarily and anonymously by the patient himself via an USB flash drive as a set of anonymized DICOM images. Therefore, no patient was ever actively involved in any part of this study.

2.3 3D Slicer

As mentioned before, the DICOM standard file format allows medical images (like MRI images) to be displayed across a multitude of electronic devices. This also includes desktop PCs and laptops. As with any other file, the device used for viewing the contents of the file must provide an application capable of reading the contents and displaying them. RadiAnt is one such program for the widely used operating system Microsoft Windows. However, RadiAnt does not provide any tools to work with the DICOM files beside viewing the image data and meta data. Since this toolset did not meet the requirements, 3D Slicer⁷ was used. Pieper et al. (2004) came to the conclusion that 3D Slicer is well suited for advanced medical image computing projects.

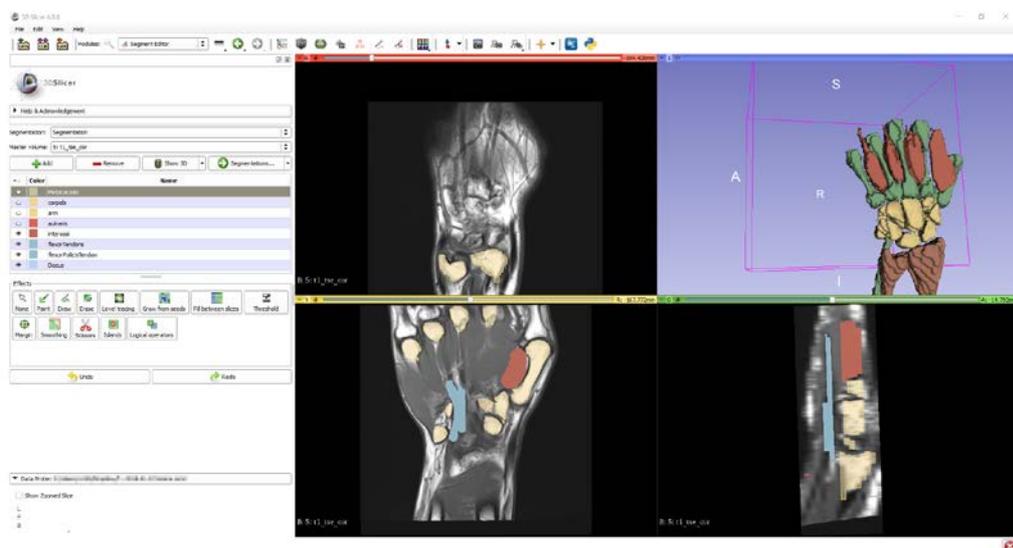


Figure 2 3D Slicer

⁷ <https://www.slicer.org/> (visited 19.02.2018)

3D Slicer is a powerful application, not only allowing viewing of the image data within DICOM files but also processing the images further. While providing many more modules, only the segment editor and the model maker were used for this study. With the segment editor it was possible to select different portions of the image and mark them as specific anatomical structures. This module, the segment editor provides several different useful tools in order to be able to select and mark the structures seen on the image. The arguably most useful tool is called the “Level tracing” tool. This tool automatically selects connected voxels of the same grayscale color level and adds them to the segment selected. However, some fine tuning may be required. Therefore, the “Paint”, “Draw”, and “Erase” tool were used (Figure 2). All of them allow the selection of a segment by simply drawing on the MRI slice. Since this task required detailed knowledge about the anatomical structures to be selected, it was most important, that a healthcare professional was performing this task. Once all the segments, which should be used within the Mixed Reality application for the Microsoft HoloLens were created, it was time to make use of 3D Slicers model maker module. This module takes the segments created before and transforms those segments into three-dimensional models. These can then be exported to OBJ-files, recognized by Unity, one of the integrated development environments used during this study for creating the Mixed Reality application.

2.4 Programming

Microsoft suggests using Unity as the preferable integrated development environment for building Mixed Reality applications for their product, the Microsoft HoloLens⁸. However, in order to be able to deploy the final software to the actual device, Microsoft’s own integrated development environment, Visual Studio, is necessary. Also, while Unity provides a simulator on its own, the HoloLens simulator, compatible with Visual Studio, is a more comprehensive and realistic solution for testing the application without having the device at hand.

2.4.1 Software used

The Unity Editor⁹ is a product of the San Francisco-based company Unity Technologies and was released in its first public version over twelve years ago. It

⁸ <https://docs.microsoft.com/en-us/windows/mixed-reality/unity-development-overview> (visited 19.02.2018)

⁹ <https://unity3d.com/> (visited 19.02.2018)

enables developers to produce virtual reality and mixed reality software on Microsoft Windows, Linux and Apple's macOS for more than 25 different platforms. Usage is allowed for personal use free of charge. While other languages were supported, the programming language used for scripting in Unity is C#.

Once a Mixed Reality application created with the Unity Editor reaches a state of stability making it suitable for testing in the HoloLens simulator or an actual device, the build menu is used to create a Visual Studio Solution, Microsoft's term for a project. Visual Studio evolved in the year 1997 from a bunch of separately sold products and became one of Microsoft's main IDEs to this date. Without further editing requirements, Visual Studio is able to deploy to a connected Microsoft HoloLens or to the HoloLens simulator, if the user opted to install it.

2.5 HoloLens

The Microsoft HoloLens are smartglasses developed since long before 2016, when the development edition of the device was launched. About a year later, Microsoft released an extended edition, called the commercial suite. This device features some enterprise features that come with Windows 10. In late 2016, Microsoft also announced, that the HoloLens would be available in countries other than the United States of America and Canada¹⁰

2.5.1 System

It's central processing unit (CPU) and graphics processing unit (GPU) are combined on an Intel chip belonging to the Cherry Trail family using a system on a chip (SoC) architecture. A system on a chip describes the method of combining different functionalities of an electronic system onto a single chip. Such a chip can combine a GPU, CPU and sensors as well as some broadcasting technologies. The CPU runs at around 1 GHz and is supported by a so called Holographic Processing Unit (HPU). The HPU is responsible for calculating and displaying the holographic projections.

¹⁰ <https://news.microsoft.com/en-au/2016/10/12/microsoft-announces-global-expansion-for-hololens/#sm.0000hacx3x7r6denyg81m2pmrthzn> (visited 19.02.2018)

2.5.2 Storage

As mentioned, the Microsoft HoloLens has a SoC, combining a CPU and a GPU, and an HPU. The holographic processing unit has its own 1 gigabyte of DRAM while the CPU and the GPU share another gigabyte of DRAM due to the SoC architecture. DRAM stands for dynamic random-access memory. The SoC and the HPU also share 8 megabytes of shadow RAM. A type of RAM used to outsource some code from a ROM for faster access. The HoloLens also has 64 gigabytes of storage, provided by an eMMC - an embedded MultiMediaCard.

2.5.3 Operating System

Microsoft's HoloLens comes with Windows 10 pre-installed. Due to the processor architecture, a 32-bit version of Windows 10 is available on the HoloLens. Although 64-bit processors were available at the time of the HoloLens' release it was not necessary to use one, because the system only has 2 gigabytes of RAM in total. A 32-bit processor can handle up to 4 gigabytes of RAM. The operating system was designed to run across a wide variety of systems. Some of which are personal computers, gaming consoles and Mixed Reality devices such as the HoloLens. This makes developing applications for the device much easier. Windows 10 supports so-called universal apps written in C# that also run across many devices, even including embedded devices like a Raspberry Pi.

2.5.4 Displays

By using stereoscopic displays, the HoloLens can provide images that are interpreted as three dimensional by the human brain. The illusion is created by using two displays. The two images projected by the two displays only differ slightly from each other. This allows the perception of depth. A human using stereoscopic displays must have stereopsis (Bredemeyer & Bullock, 1978, p. 69), the ability to combine the two images with two healthy eyes. A health human being has all of these prerequisites at their disposal and can therefor handle stereoscopic vision.

2.5.5 Controller

Instead of relying on hardware controllers, most of the input on the HoloLens is done by natural actions of the human body. Other devices like the HTC Vive come with two accessory devices that allow the user to interact with the virtual objects. Microsoft chose to allow the user to use only their hands and voice in combination with their gaze for most of the interactions. The HoloLens has five buttons built into the headset. Two on each side and one at the back. The last

one acts as an on and an off switch. The two buttons on the left allow manipulation of the screen brightness. Those on the right side are used for altering the volume of the built-in speakers. Other than those five buttons, gestures and voice commands are used to send commands to the device.

In particular, there are two default gestures. The first one is called the *bloom gesture*. Its name derives from its looks. By duplicating the opening of a blossom this gesture simulates the blooming of a flower. It's used to open the main menu. The second gesture could be seen as the more important one. It's titled "Air Tap" and is used to interact with the virtual elements fixated by the user. By first making a fist and forming an "L" with the index finger and the thumb and then in the second step briefly pinching those two fingers together, the "Air Tap" gesture is executed.

While Microsoft states it uses the users gaze to determine which virtual element is the object of interest, they are really just using the users head movements, since no sensor, capable of tracking the user's eyes is built into the device. The HoloLens displays a white dot in the middle of the screen, visualizing the headset's center of attention and thereby its gaze. By moving the head in three-dimensional space, this center of attention can be moved freely. It's best to imagine a stick of infinite length coming out of the middle of the device. Whichever virtual object this stick impales is the object of interest for the HoloLens.

Finally, Microsoft has also built in their speech assistant known by the name "Cortana", named after the virtual assistant accompanying the protagonist of Bungie's video game "Halo". "Cortana" can be used to "click" on buttons in the menu by saying the button's caption. It's also possible to start the recording of a screencast within an app by using "Cortana".

2.5.6 Camera

By including a depth camera, Microsoft added a very useful component for a Mixed Reality device to the HoloLens. This camera allows the device to produce a range image and do spatial mapping. The software interprets the created image and can then integrate virtual objects into the real world by considering surfaces of the user's real environment. Spatial Mapping is one of the most advertised selling points of Microsoft's HoloLens. Also, the device features a 2.4-megapixel camera and an ambient light sensor.

2.5.7 Sensors

The device makes use of a so-called inertial measurement unit which consists of all sorts of different sensors. Firstly, the device uses an accelerometer. This sensor calculates a body's acceleration by considering fictitious force (Tickoo & Iyer, 2016, p. 25). Secondly, one or more gyroscopes are built into this inertial measurement unit. Gyroscopes measure not only a body's velocity but also its orientation. Typically, electronic devices, like a smartphone or smartglasses do not use a traditional gyroscope, made out of a disc, but rather a MEMS gyroscope. MEMS stands for microelectromechanical system (Tickoo & Iyer, 2016, p. 24) and are used on many occasions today, gaming being one of the more popular use cases. MEMS gyroscopes are integrated circuits, like a 555 timer. Although being an integrated circuit is the only thing those two ICs have in common. The HoloLens even features a magnetometer - a compass¹¹.

2.6 Implementation

Programming a Mixed Reality application involves understanding the environment the software will be used in at the very beginning. Then, the developer must understand the target group and their needs. After that, it is important to know the capabilities of the target device and the used programming language. The software itself needs considerations, too. While it is very clear how to design a user interface for a smartphone app, a Mixed Reality application allows much more freedom. However, it also requires the developer to think about the freedom of the user. What should the user be able to do and how should one enable the user to do so? Those are two central questions when designing not only Mixed Reality software, but software in general. Finally, the process involves testing the prototype in the targeted setting with or without the users this product is made for. This part of the master thesis will go over each of those steps in detail and describe the process from a blank canvas to the final prototype. Figure 2 shows the finished software in Unity's integrated simulator.

¹¹ <https://blogs.windows.com/devices/2015/04/30/build-2015-a-closer-look-at-the-microsoft-hololens-hardware/> (visited 19.02.2018)

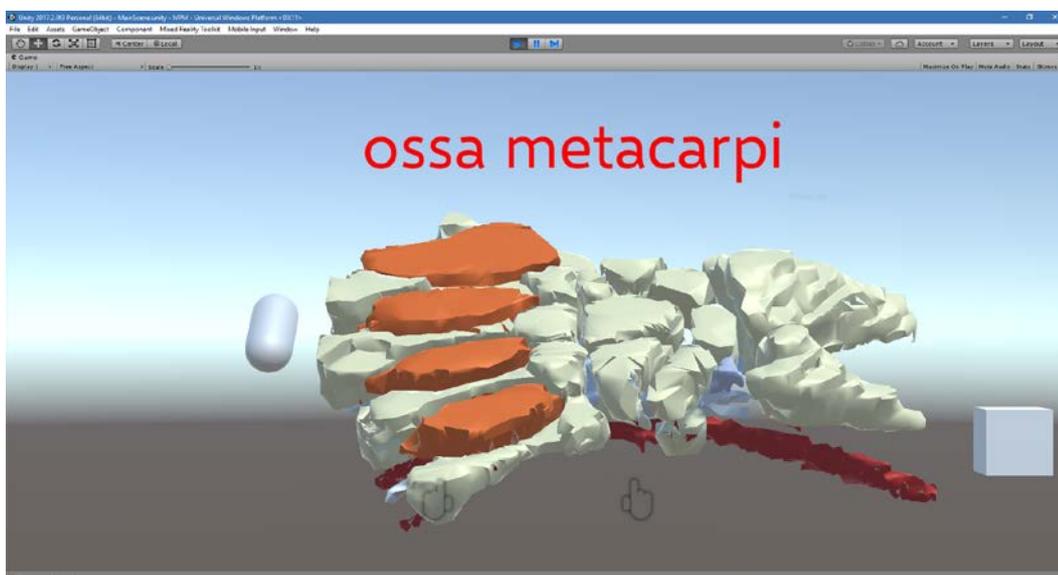


Figure 3 *The model of the hand in Unity's integrated simulator.*

2.6.1 Environment

Choosing the right environment not only involves some knowledge about the target group, but also needs consideration about how the software will be used and what it will be used for. The software was meant to be a learning tool for physiotherapists and occupational therapists. It would have elements of a human hand placed inside three-dimensional space. Those elements should facilitate the understanding of MRI images and help therapists with learning anatomical structures of the human musculoskeletal system. Therefore, another consideration had to be made. As stated in the literature research, scale is one of the features of Virtual Reality (Sánchez et al., 2000). How should one scale the elements of a human hand?

2.6.1.1 Model scale

The bones, tendons, cartilages, vessels and muscles could of course have a life-size scale. This model of a hand would be placeable on tables, beds, the floor, examination and treatment beds or somewhere in the air. The learner would then be able to walk around the model and see it from different angles. This would also allow the student to see the full model without stepping too far away. The limited field of view which requires stepping away in order to see the full model is caused by the hardware limitations of the Microsoft HoloLens. Small structures like the processus styloideus of the metacarpus would be barely visible when choosing this sort of scale. Also, interaction with the model would be highly aggravated due to the small size of single elements, like the discus

interarticularis. Since the cursor of the Microsoft HoloLens is tightly tied to the head movements of the carrier, fixating the white dot representing the cursor would be hardly doable.

Considering the limitations of the life-size model, an over-sized model is the next logical option. The over-sized model would be about the size of a grown up and therefor still can be placed in a room. The participants would be able to walk around the model and change the viewpoint accordingly. These two features of the paper of Sánchez et al. (2000) are therefore fulfilled. Let's look at the remaining ones. Interaction also benefits from a larger model. The discus interarticularis of the human hand is about the size of raspberry, depending on the size of the human it originates from. As mentioned before, interacting with an element this size would be extremely difficult due to the way, the user interacts with objects using the Microsoft HoloLens. However, making the cartilage the size of a human fist makes interacting with the element a lot easier. Integrating a model this large in the simulation not only adds the requirement of a larger room but also shows the limitations of the HoloLens. One would have to look at the hand from a distance in order to look at the whole model.

2.6.1.2 Room

All the considerations about the model size taken into account, it was decided to use an over-sized model of the human hand derived from the MRI images. What kind of room would be suitable for a simulation containing a huge model of parts of the human hand? The right room to use is not only dependant on the model used but also on the context in which the learning takes place. Again, one needs to think about the natural environment of the users, which in this case are physiotherapists and occupational therapists. They both work in a wide range of different rooms. While many therapies take place in a single-therapy room some therapies of both professions are held in a gymnastics room. The single therapy room would be big enough for a life-size model. It would also allow the placement of the model on different kinds of surfaces like the desktop, a therapy bed or a shelf next to a sink.

The gymnastics room available to the study leader is a large room containing different objects used by the therapists during therapeutic sessions. Thanks to the mobility of all the machines and objects used by the therapists in the gymnastics room, it was possible to create a large free space within this room where the hand could be placed. The participants would be able to walk around the model of the human hand and change their. The participants would however also be able to place the hand on any other surface than the floor since a therapy bed and a desktop were available to them. The gymnastics room would allow all

the features of a Virtual Reality application to be used while still taking the natural setting of the therapists into account.

2.6.2 Target group and setting

The final product, a prototype in this case, targets persons who either are studying to become or already are physiotherapists or occupational therapists. However, the study only targets persons who already are therapists in their respective field. Evaluating the software requires the user or the participant to already know what one would expect from a medium trying to facilitate learning and understanding anatomical structures and MRI images. The decision is based on the experience that persons familiar with a certain topic can better articulate what could be improved.

2.6.2.1 Professional fields

Physiotherapists and occupational therapists both are healthcare professionals. In Austria the two professions are so-called MTDG professions. MTDG stands for “Medizinisch Therapeutisch Diagnostische Gesundheitsberufe” which translates to medical, therapeutical, diagnosing healthcare professions. While this software is clearly not aiming for facilitating diagnosis of anomalies of the human musculoskeletal system, a better visual understanding of anatomical structures helps those professionals. The usual perception might be that physiotherapists mostly treat the core and the lower limbs while occupational therapists are specialized on the upper limb and cognitive training. This is not entirely true. Both professions work with patient’s upper limbs. Physiotherapists as well as occupational therapists have highly specialized knowledge about the upper limbs and especially about the hands.

This includes the knowledge about the muscles, the bones, the cartilages, the nerves and the blood vessels. Both kinds of therapists know exactly which nerve innervates which muscle and which muscle connects to which bone and where it connects to the bone. They know about courses of nerves and blood vessels. Also, the therapists know about the relations of all the structures to one another and how the human body is connected and works as a whole. Before they know all this, they undergo a three-year training at a university of applied sciences which also involves the studying of the human anatomy. Most students have the opportunity to work with models or in some cases even real parts of the human body. And while both methods, working with plastic models and human corpses, allows the students to feel and interact with the structures, a Mixed Reality environment could further improve this experience. The human hand was chosen

because both physiotherapists and occupational therapists have detailed knowledge about this exact structure.

2.6.2.2 Level of detail

The level of detail of the model also addresses the professional fields of the therapists. Muscles were included because the therapists are, depending on the patient's problem and diagnosis, working on the improvement of the patient's stamina, strength or coordination. All three of those tasks involve muscles and nerves. Without appropriate blood supply, no part of the human body would be able to work the way it is supposed to work. A physiotherapist and an occupational therapist are both trained to be able to treat reduced blood supply. Different techniques, like trigger point therapy, massages and active exercises all aim to improve the blood flow and require a thorough understanding of the human body and its musculoskeletal system. Also, understanding where tendons are and what's their course improves the understanding of human physiological and pathological movement.

Based on these considerations the parts to be extracted from the MRI were chosen. The virtual model of the human hand includes muscles, tendons, cartillages, blood vessels and bones. Each of them true to scale to ease the understanding of the relations of different parts of the human hand and of course to empower the student or the learner in general to understand the functions of the human body.

2.6.3 User interface

The interaction can happen on at least two different layers in this application. The first layer is the sensomotory layer. The user is able to walk around and see the virtual elements of the hand. On the other hand, the user can also interact indirectly with the anatomic structure by clicking buttons in order to rotate and relocate the mesh.

2.6.3.1 Descriptive text

In total there are four ways in which the user interacts with the model or the model interacts with the learner. First of all, the player can display a description of the object at the center of the field of view. This description displays the Latin name of the anatomical structure the learner is currently focusing on. It is displaying the descriptive text in red letters, floating at the upper border of the screen. Many considerations were made before finally deciding for this visual approach. The text needed to be visible in any condition imaginable. It was also

considered to put the text inside an opaque textbox. However, this approach might have covered large parts of the screen and also parts of the structure the student is learning about. The text is moving with the rotation and movement of the Mixed Reality headset. It is not attached to the object the user is looking at.

Listing 1 *Update()-method of "DisplayHint.cs"*

```
void Update ()
{
    RaycastHit hitInfo;
    if (Physics.Raycast(
        Camera.main.transform.position,
        Camera.main.transform.forward,
        out hitInfo,
        20.0f,
        Physics.DefaultRaycastLayers))
    {
        if (labels.ContainsKey(hitInfo.collider.name))
        {
            hintBox.text = labels[hitInfo.collider.name];
        } else
        {
            hintBox.text = "";
        }
    } else
    {
        hintBox.text = "";
    }
}
```

Listing 1 clearly shows why it is more convenient for programming to have one UI element that gets updated, depending on the object in focus instead of the other approach. The contents of the UI text elements are updated with the name of the structure, the cursor is resting on. This text is always facing the person and it is usually above all other elements. Since regular UI elements (as provided by the Unity Editor) are not compatible with the Mixed Reality applications, this custom UI text element is positioned relative to the camera (in this case the HoloLens). When a user get so close to an object that it is closer to the camera than the text, the text is not visible any more. This is detached from the viewpoint of the user. An approach where the text is attached to the element would not only require the developer to rotate the textbox accordingly but also to consider the viewpoint. If the user is looking at the object from above and the text is located above, updating the scene would involve more complex calculations

The scene contains a HUD object which has the Script “DisplayHint.cs” attached. “DisplayHint.cs” sends out a raycast on every frame update and checks what the raycasts hits. If it hits an anatomical structure, the script knows which one and alters the text in the textbox accordingly. The dictionary containing all the descriptive text linked to the tag names is set in the *Start* method of the script. If the raycast collides with one of the actual UI elements or nothing at all, the textbox will be blank.

2.6.3.2 Rotation button

This very simple method (Listing 2) rotates both objects, the hand and the pill by the value of the variable *degToRotate*. The variable holds the integer 45 by default, which results in a rotation by 45 degrees.

Listing 2 *OnInputClicked()*-method of “RotateObject.cs”

```
public virtual void OnInputClicked(InputClickedEventData eventData)
{
    elementsToRotate.transform.Rotate(degToRot, 0, 0);
    this.transform.Rotate(degToRot, 0, 0);
}
```

When designing the rotation button, there were three different options at first. The first option was to create a custom gesture that the user could perform with their hand which would then either bring up a menu allowing the users to choose what would happen next or perform a specific operation like rotating the object. However, as stated in the forums, it is discouraged to come up with custom gestures as it would bring another layer of complexity to handling their product. Also learning another gesture would add another layer of complexity to the software itself. This would go against the considerations made at the very beginning of the project. The questionnaire also evaluates the complexity of the software.

The second option was to create a button that is floating next to the virtual hand which would have a caption. This caption would indicate what would happen once the button was clicked. However, this option needed further consideration since the caption would have to be in a certain language. Of course, the application could be multi lingual and make the user choose the language whenever they start it. This however, would again add a layer of complexity which is not welcome.

Option number three involved a shape that could easily indicate the possible rotations. This shape should also represent a handle the user would instantly recognize as something they could touch and turn. While a twisted arrow would clearly indicate the ability to rotate, it imposed another problem. The arrow would be too hard to focus on with the HoloLens' cursors because of the nature of the shape. A pill shaped object like the one used in the final prototype was placed at one end of the virtual hand.

2.6.3.3 *World anchor*

One feature of the application would allow the users to relocate the model of the virtual hand anywhere in the room they are in. This was made possible by the spatial mapping feature of the HoloLens. However, an object symbolizing an anchor was required in order to implement this feature. A three-dimensional anchor was considered to be a clear symbol. A cube however, seemed more appropriate. The flat characteristics of the cube seemed to better represent the features of this anchor. It would symbolize its ability to place the elements of the hand in the real environment much like a socket would allow the placement of a figurine. But the cube was less intrusive than a socket which should have spanned over the whole width of the model of the hand. Luckily, Microsoft ships their Mixed Reality Toolkit with a script easily attachable to game objects which allows the relocation of objects. Said toolkit will be covered in a later chapter of this thesis.

2.6.3.4 *Toggling the opacity of the elements of the hand*

Being able to toggle the opacity of specific, selected elements of the virtual model of the human hand distinguishes the Mixed Reality implementation from a plastic model in the real world. The learner can simply switch single bones, tendons, cartilages, muscles or vessels on and off and can then see what lies underneath them. This might help students to better understand the relations of the different anatomical structures. Another option was considered before implementing this feature. Instead of toggling the opacity of the structure, the user would change the color in order to highlight it. This idea was not implemented. However, it might, be a feature worth considering for a similar software targeting teachers. This feature would allow teachers to highlight the structure they are talking about.

The final implementation of this feature requires the user to look at the structure they want to change the opacity of and then perform an "Air Tap" gesture. This triggers a script to change the material of the element of the hand to a separate material, which has the same color but has a different alpha level. It turned out that this realization of the feature worked well with the Mixed Reality

environment. Other ideas involved, again, creating a custom gesture which would open a menu allowing the user to select the opaque elements. This however seemed very unnatural and would add an unnecessary layer of complexity, too. Therefore, the anatomical structures of the human hand are not only observable objects but also elements of the user interface. This allows the user to touch the elements to some extent and integrates a sensomotory experience into the Mixed Reality application.

2.6.4 Testing

There were three possible testing solutions available for testing the Mixed Reality application. First, minor changes can be tested with Unity's built in simulator. This allows for rapid testing of simple changes like color alterations or text adaptations. The simulator built into the Unity Editor however does not support all of the features of the Microsoft HoloLens like spatial mapping. Testing the software with the Microsoft HoloLens simulator is a good idea and highly encouraged in order to deliver a stable application. The simulator seamlessly integrates into Visual Studio as a deployment target. Spatial mapping and the generic HoloLens user interface are the major advantages. The emulator requires Hyper-V, a feature only available to some Windows 10 editions. This narrows down the possible development environments for Mixed Reality applications. The third way to test is to use an actual device. All three of the testing options named above were used by the author of this master thesis.

2.6.5 Obstacles during development

Working with rapidly evolving technologies always comes with obstacles. One of the main hurdle to overcome was getting started. Searching for tutorials and "getting started" articles on the Microsoft HoloLens, the Mixed Reality Toolkit and its integration into the Unity Editor revealed only a small number of pre-existing solutions. The problem with the articles and instructions found was that they were related to an earlier version of Unity Editor or the Mixed Reality Toolkit. Since those two packages changed dramatically over the last few months, the tutorials were not always relatable. It required the developer to figure out how to use the device in conjunction with the IDE and then again, the IDE with the toolkit by trial and error.

The Mixed Reality Toolkit is an open sourced asset package for Unity Editor released by Microsoft on GitHub under the MIT license. It adds features to Unity, which facilitate the development of Mixed Reality applications for the Microsoft HoloLens and also adds some useful premade scripts. Those scripts allow, for

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example, to easily define an object as a world anchor and enabling the “Tap to Place” functionality. A functionality which is the same across all HoloLens applications.

3 Assessment

3.1 Inclusion criteria

Physiotherapists and occupational therapists of any age are allowed to participate in this study. The probands have to have average eyesight. There are no restrictions considering walking disabilities as the software can also be used in a sitting position, for example a wheelchair. The physiotherapists and occupational therapists participating must either have been working as a therapist within the last year or be about to work as a therapist within the next 365 days. The reason for this is that the first group of possible participants has to or had to deal with anatomical structures in a somewhat recent time period. The second group of possible participants is about to refresh or in the process of refreshing their knowledge of anatomical structures.

3.2 exclusion criteria

Students of physiotherapy and students of occupational therapy are not allowed to participate in the study, because they are in the process of learning anatomy. This circumstance could influence the outcome of the study. Also, therapists with severe visual disabilities, like blindness, are not allowed to be part of the study as the software gives visual input.

3.3 Study design

This study is a descriptive study. The participants were able to try out a prototype of a Virtual Reality application. After a five-minute try-out phase, the participants were asked to fill out a questionnaire based on the ISO 9241/10 standard. The results deriving from this questionnaire were inspected by the study leader and subsequently described in the results section of this master thesis. Thorough examination of the data provided by the inquiry allowed to come to a conclusion and think about the next steps necessary in order to add improvements to a follow-up study.

3.4 Procedure

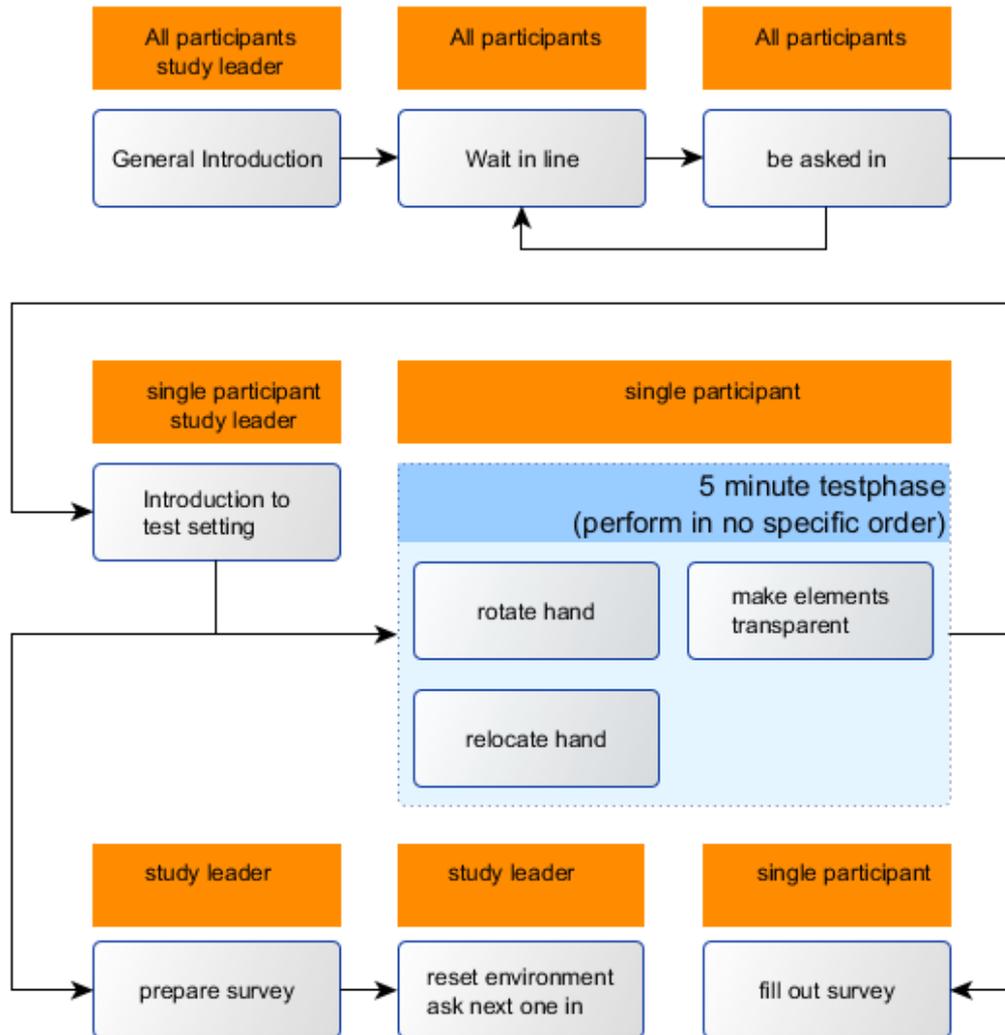


Figure 4 Visualization of the procedure

After the procedure had been planned by the study leader, an e-mail was sent out to a list of physiotherapists and occupational therapist living in Vienna or the greater metropolitan area including suburbs and surrounding counties. This restriction was due to the place where the study was carried out also being in Vienna. The e-mail contained the request for participation in the study, a short description of the contents of the study and exclusion and inclusion criteria. In the e-mail the recipients were told a date when the testing would take place. Also, the e-mail informed the persons receiving the e-mail about possible health hazards imposed by the device and the nature of the application. While the email reached twenty-four possible participants, only eighteen answered with a positive

response. The other six receivers either denied participation in the study or did not respond at all. Two of the participants originally offering to participate in the study dropped out due to illness. Therefor only sixteen of the people contacted in the first place tried out the Mixed Reality application installed on Microsoft's HoloLens and filled out a questionnaire afterwards. None of the participants trying out the software refused to fill out a questionnaire.

Table 1 *Participants*

	Percentage	Count
e-Mails sent	100%	24
Positive answers (Response rate)	75%	18
Negative or no answers	25%	6
Participants dropped out (drop out rate)	8% (2 of 24)	2
Filled out questionnaires	66% (16 of 24)	16

All of the participants gathered in a gymnastics room with all of the interfering objects moved to the side of the room in order to have enough space for the holographic projection. Of course, there was enough space to walk around the projection too. Before the participants were present, the study leader already prepared the Microsoft HoloLens to not confuse the subjects by first having to prepare the setup. Once the participants were ready, a general introduction was given. This introduction contained information about the contents of the application, the device, safety and health regulations and the further procedure. The participants were told that they are about to see a holographic projection of the metacarpus, the carpus, pieces of radius and ulnar, parts of two tendons and part of an arteria of a human hand. It was also mentioned that they would be able to rotate the hand and make elements or groups of elements of the hand transparent (Figure 4).

3 Assessment

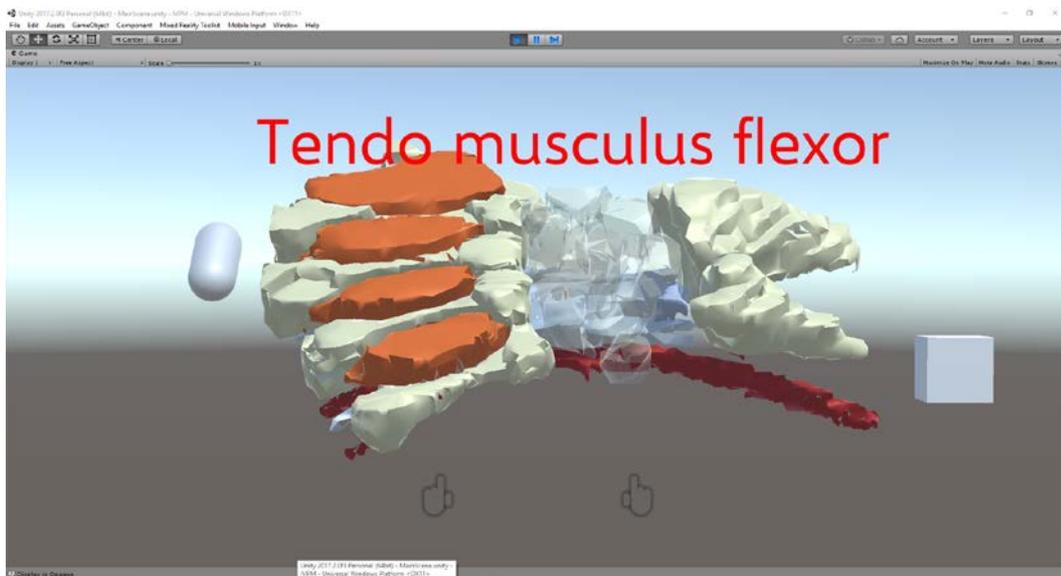


Figure 5 Rotated model of the human hand with some elements transparent.

After the introduction the participants also knew that the hand can be approached in the real world since the virtual object is anchored in the real world. During the introduction it was pointed out that the device they were about to wear can in some cases cause seizures and vertigo. Details about the handling of the device and gestures to interact with the software were not part of the introduction but were the content of a secondary introduction given to each of the participants right before they tried out the device. This secondary introduction would take place in the gymnastics room but with nobody aside one participant and the study leader present. The other participants would wait in a queue before the gymnastics room. The participants were told, that once five minutes have passed they would be asked to unmount the headset and fill out a questionnaire in another room.

After the general introduction, the first participant was asked to enter the gymnastics room. The subject was shown the HoloLens again with particular attention on how to mount the device and fit it on one's individual head. Once the already turned on device was mounted, the study leader asked the participant to look in the direction where the hand was placed beforehand. Attention was the brought to the white dot in the middle of the field of view, representing the cursor. The participants were informed about the function of the point and how to use it in combination with the "Air Tap" gesture. After the explanation of the "Air Tap" gesture, the participants were told about what would happen when specific virtual elements they were seeing would be interacted with. Once the participant felt comfortable with handling the software, they were allowed to move freely in the

gym and interact with the virtual objects the way they wanted. After five minutes the participants were asked to finish what they were doing and unmount the headset. They were then guided to another room where the questionnaire was ready to be filled out on a computer. A trusted person was supervising the participant filling out the questionnaire and preparing the computer for the next participant once the participant currently evaluation the software was done doing so. Before the next participant was asked to enter the gym, the study leader undid all the changes, the previous participants had done within the app in order to create the same experience for all participants. This procedure was repeated for all 16 participants (Figure 3).

3.5 Questionnaire

Relying on proven concepts is rather important. That's why a modified version of the German questionnaire based on ISO 9241/10 was the survey method of choice. A German version of the questionnaire was chosen because all of the subjects evaluating the software have German as their mother tongue. While most of the question of version of the German questionnaire based on ISO 9241/10 fitted the use case, some did not. Those were removed from the German questionnaire based on ISO 9241/10¹². This resulted in a modified version of the ISO 9241/10 questionnaire which was further altered.

The original questionnaire used a seven-step scale for answering the questions. The modified version used in this study only uses a five-step scale. This was done due to usability concerns. A five-step scale was found easier than a seven-step scale and was therefor preferred for this study and subsequently used.

The questionnaire used in this study is separated in seven main segments. Six of those seven segments are based on the ergonomic norm ISO 9241/10. The seventh section asks special questions, created especially for the software used in this study and the research question addressed in this master thesis, in the style of the other six parts. In the beginning an extra section explains how to answer the questions by providing an extraordinarily simple, custom question that also resembles the style of the six ISO 9241/10 passages. In the end some demographic questions are asked in a separate, additional segment.

ISO 9241 describes an international standard concerning interaction between humans and systems, like computers or other instruments and machines. The

¹² <https://www.iso.org/standard/16873.html>

standard was set by the International Organization for Standardization which was founded in 1947 after its predecessor, the International Federation of National Standardizing Associations was suspended during the second World War in 1942. Today, it sets standards in 162 countries around the globe. Since the year 2000 the norm is known by the number 110 and does not only concern software but also hardware. In this study the questionnaire based on the ISO 9241 norm is used to evaluate the application's usability and also if it can fulfill the intended tasks.

The questionnaire in its original form was designed as an evaluation instrument that is economical to use (Prümper, 1999). Prümper (1993) targeted prototypes, existing software and discussion groups. It is based on the seven dialog principles mentioned in the ISO 9241/10 norm and therefor is separated into seven segments each containing several questions. In its standard form the questionnaire provides a seven-step scale to answer all the questions. The seven dialog principles are "suitability for the task", "self-descriptiveness", "controllability", "conformity with the user expectation", "error tolerance", "suitability for individualization" and "suitability for learning". The questionnaire used in this study is a slightly customized variant of the German version by Prümper¹³.

3.5.1 Used segments

The adapted questionnaire used in this study does not make use of all of the seven dialog principles but only of six. The dialog principles taken into account for the customized version of the questionnaire are "suitability for the task", "self-descriptiveness", "controllability", "conformity with the user expectation", "error tolerance" and "suitability for learning". The one dialog principle that was left out was "suitability for individualization" because none of the provided questions seemed suitable for the provided software. In the following, this study will go over the segments and its questions in detail, explaining the intention of the selected questions. Please refer to the questionnaire in the appendix while reading the description of the questions of the segments.

3.5.1.1 Suitability for the task

The segment's first question asks whether the software is complicated to use or not complicated. This is probably one of the most important questions in the

¹³ http://www.ergo-online.de/site.aspx?url=html/service/download_area/isonorm.doc
(visited 19.02.2018)

whole questionnaires. The software evaluated in this study should provide an easy method for students to learn anatomical structures and to learn about MRI images. If the software itself must be subject to its own classes in order to be able to use it, its usability would certainly be heavily limited. The second question questions the possibility to automate certain tasks within the app. It is used to ascertain the need of such a function. Finally, with the third question it is asked if the software requires the user to make redundant inputs. This also emphasizes the importance of ease of use. The more the user has to make redundant inputs the more it stops them from actually using the application. Since the programs use case is to enrich the learning experience, this is another very important question.

3.5.1.2 Self-descriptiveness

The software evaluated during this study should serve a special purpose. The targeted users of the software are learners. With this application for Microsoft's HoloLens, learning anatomical structures and understanding MRI images should be facilitated. Having to learn about how to use software with the only purpose of learning things is therefore not what the designer of such software would ever intend. It is immensely important that the software has a high rate of self-descriptiveness. This segment of the modified questionnaire poses five questions.

The first one evaluates whether the software gives a good oversight over the feature set. The software's feature set basically consists of four features. The user can place the virtual elements freely in the real environment. Also, the user is able to rotate the virtual elements by executing the "Air Tap" gesture while placing the cursor on a pill shaped object. The third feature describes the possibility to change the opacity of elements by also performing the "Air Tap" gesture. Finally, one of the most important features is the ability to walk around the real environment and look at the virtual object from any angle. The participants were asked to select an answer on the scale from one to five based on their experience.

The application for the Mixed Reality device uses two symbols that allow the interaction with the model. A cube is used to symbolize the anchor. The anchor is used to move the virtual hand freely in the room once it's been activated by the "Air Tap" gesture. Also activated by the same gesture is an object resembling a pill. This object is used to rotate the virtual elements of the hand. The rotation of the pill always reflects the rotation of the virtual anatomical structures. The second question of this section of the questionnaire lets the participant decide if

the software uses easily understandable words, descriptions or abbreviations in menus.

When it comes to usability, it's very important to inform the user about legal and illegal actions. The third question is about this issue. Does the software give enough information about what can or cannot be done with the application, the fourth question asks. The fifth question turns to the same topic. It evaluates if the software gives context sensitive explanations when asked. Also, these explanations should be helpful in order to reach a score of five of five points. The sixth question goes one step further. Here the question is whether the software explains context-sensitively the situation without the user asking for help. Again, the questions should be helpful for a full five points rating.

3.5.1.3 Controllability

Some applications are very rigid in the way they operate. Good software accommodates to the needs and the procedures of the user and not vice versa. Bad software on the other hand requires the user to do tasks in a specific order. It can get even worse. The software could require the user to do things in a specific order while not telling the user about the order of the tasks. This section's first question asks if the software allows the user to stop whatever the user is doing and continue from exactly that state on a later point in time. The user should not lose any progress by stopping to use the software and continue later on. Also, this section evaluates if the software makes the user follow strict procedures in order to use the software productively and correctly. Subject of this section also is the customizability of the interface. Can the user influence which information is visible on the screen, is the content of the third question. Lastly, the questionnaire finishes this part of it by finding out if the software requires the user to bring their workflow to a complete halt when it would actually not be necessary. This can happen if some software requires the user to do an input not directly related to the currently performed task.

3.5.1.4 Conformity with the user expectation

Whenever a user first uses an application, the user has some kind of expectations based on the icon, the name or the description of the piece of software. That however is just one kind of expectation. The user expects software to behave in some way based on their experience with the same application. Clicking a button should always result in a similar action. An application should also follow consistent and uniform guidelines. An inconsistent design of an application makes it harder to productively use it. The first question

is about this topic. The fourth question asks for uniform principles and therefore also tries to look into this topic.

The second question refers to another section of this modified questionnaire. This question allows the participant to decide if the software leaves user in the dark whether the interaction was successfully processed by the software or not. This expands on the question of the segment “self-descriptiveness”, asking if the software states clearly which interactions are legal or not and further evaluates the usability of this specific aspect of the software evaluated by this questionnaire.

Users expect applications usually to be fast and not to need long processing times. Of course, those processing times can vary based on the given task. If such a processing task would take longer than usual, it’s always good to inform the user about this prolonged time. The third question asks the participant if the application reacts with predictable processing times when the user interacts with the software.

3.5.1.5 Error Tolerance

This segment of the modified questionnaire only consists of two questions, both considering the error tolerance of the software. Everyone makes mistakes. Especially when using a new, unknown application, errors are not uncommon. Errors can, in the worst case, result in crashes of applications. Those would heavily influence the user’s workflow. Unit and integration tests can prevent such crashes and indicate so called edge cases. Edge cases are use cases that are not intended by the developer and it is unusual the user would ever use the software in such a manner. When designing a software, edge cases are always worth considering. An error message is always better than a software crash. Software that gives error messages instead of crashing, can be considered more tolerant towards errors.

The first question asks, if a small mistake leads to severe consequences or not. It obviously has a great influence on the usability of an application when a click on the wrong button at the wrong time leads to a system crash. The second question evaluates the next step. Does it take great expenses to correct the consequences once an error has occurred? A software crash can have a small impact like only the crash itself or severe impact when the crash also corrupts a database or a file system. Simply restarting the application requires little expenses from the user while restoring a database from a backup or – even worse – having to set up the whole database again can be a huge workload.

3.5.1.6 Suitability for learning

This segment is one of the most important segments of the whole modified questionnaire. It consists of a total of five selected questions from the source questionnaire. The segment's questions evaluate if the software used in this study allows the user of the application to simply use it or if it requires them to invest time or other resources into getting to know the software and its handling. Actually, the first question already asks, if the software requires little or much time to learn how to use it. Again, this software is intended to help students and learners to learn about anatomical structures and MRI images. Therefore, having to learn how to use the software would impose unnecessary obstacles on the user and should be avoided where possible.

The second question wants the participant to think about if and how the software encouraged them to try out new or – to the user – unknown features. The pill shaped object reflecting the rotation of the virtual hand was designed to encourage the user to perform an “Air Tap” gesture on it. Because this object could not only resemble a pill but also a handle to some users, this form factor seemed more than appropriate to represent this function. Also, the cube as a symbol for the anchor was chosen for a reason. The flat surface of the cube was meant to make the users recognize it as something that could be put on the floor.

In this application, only three major objects were used and simultaneously are on the screen. Aside from the pill shaped object and the cube shaped object, there only were the elements of the hand. Those were the only clickable objects and therefore the only things the user could interact with. The third question asks if there are many details to memorize in order to use the application.

Lastly, this section of the questionnaire questions the need of a manual and the memorability of said details. This question has a lot in common with the first question. Details used in software, like buttons or drop-down selects should be meaningful in order to be memorable. If that is not the case, the people using the software might have to repeatedly learn and memorize the details used to interact with the software. Also, a manual can be a good indicator, stating that the software in question is too difficult or the interface or the workflow are too complex to understand by simply using the application. The Mixed Reality software used in this study only required the user to understand and memorize the “Air Tap” gesture for software interaction.

3.5.1.7 Individual Questions

Since usability is only one part of the scientific question of this study, the last segment of the questionnaire tries to find answers to the question whether the

application is useful in an educational setting for physiotherapists and occupational therapists or not. How does the Mixed Reality environment change or enhance the learning habits of physiotherapists and occupational therapists? This question is of course posed with a focus on the understanding of MRI images and studying anatomical structures. Naturally, the first question asks, if the software can help a physiotherapist or an occupational therapist when they are learning about anatomical structures such as the metacarpus, the carpus and forearm.

As described in another part of this master thesis, the three-dimensional objects used in the Mixed Reality software derive from the DICOM data of an MRI. Therefore the whole software can be seen as a visualization of black and white MRI images. This, of course, is only one approach to visualize MRI images. The second question evaluates this approach by implicitly asking if the software provides a good or bad visualization of MRI images. As with all the other questions, the participants were given a scale reaching from one to five to answer the question with.

The last two questions aim at a radical but not impossible way of changing how to learn about anatomical structures, MRI images and anatomical structures with the help of MRI images. The quite radical assumption that those questions are based on is, if the software in this currently available form can replace MRI images as known. MRI images at this time are either printed on paper with each slice next to another or presented in a software that allows scrolling through each slice, one at a time. The fourth question asks the participant to select on a scale from one to five if the software presented can or cannot be an alternative to MRI images in a learning setting. Question number five asks if the software that the participant just used offers all possibilities an MRI image offers, while learning anatomical structures or none of the possibilities.

4 Results

The participants of the study were handed a questionnaire after they tested the software. The goal of the questionnaire was to evaluate the usability of the software for the use in an educational setting. This was done by using the ISO 9241/10 questionnaire. Although, the questionnaire is described in a chapter before, it will again be called in remembrance in the following chapter. Every question could be answered on a five-step scale.

The box plots below require a little explanation. While the line within a box is located at the median's value, a cross marks the mean. Outliers are symbolized by dots. Upper and lower whiskers are depicted as T-shaped lines in the color of the box they belong to. The box is terminated by the third and first quartile respectively, as usual. Keep in mind that sometimes multiple markings can have the same value due to a relatively small dataset.

4.1 Questionnaire

4.1.1 Suitability for the task

This set's first question asked for the difficulty of the software and if it was hard or easy to use. Only two persons rated the software a three on this five-step scale which represents average. The majority of the participants rated the software four and above, stating that the software is easy or even very easy to use. Question two asked the participants if the software allowed the users to automate certain tasks. Since the software itself did not allow any kind of automation, the question left room for interpretation. Hence, the wide variety of ratings. The question could ask if the software is designed to train some kind of automatisms or if the software allows automation. Question three on the other hand is very clearly rated. If the software required any unnecessary inputs, was the question. Since the software only required inputs for interaction with the model, this clear answer was somehow expected.



Figure 6 Box plot depicting the results for the question set "suitability for the task"

4.1.2 Self-descriptiveness

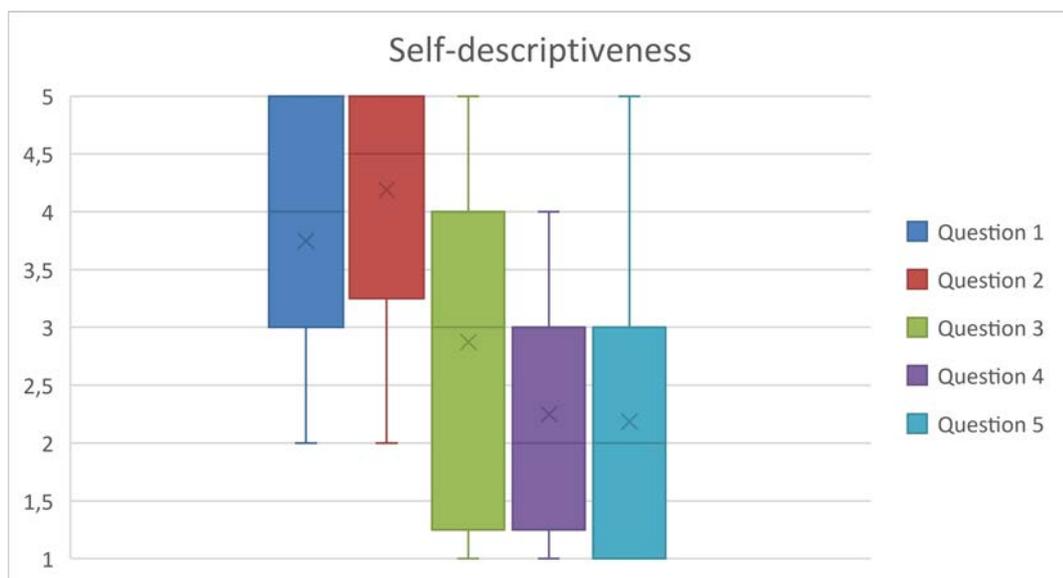


Figure 7 Box plot depicting the results for the question set "self-descriptiveness"

Self-descriptiveness is a set of questions, evaluating the software's ability to be easily understandable without the need of a complementary instructions manual or further explanations. As the box plot shows, this seemed not to be the case for all participants. But still, there is some homogeneity. Question one, asking if the software gives a good overview of the available features, was answered mainly positively. The second question, which asked if the software uses the same

symbols and language throughout the application in order to make it more useable, also was answered mostly positively. The participants had very different opinions, whether the software was clear on which actions are legal or illegal. This was asked with question three. Most participants however agreed that the software did not offer any explanations when those were needed. The software also couldn't answer specific questions which would help the users. This might give an explanation to the negative response to answer number five.

4.1.3 Controllability

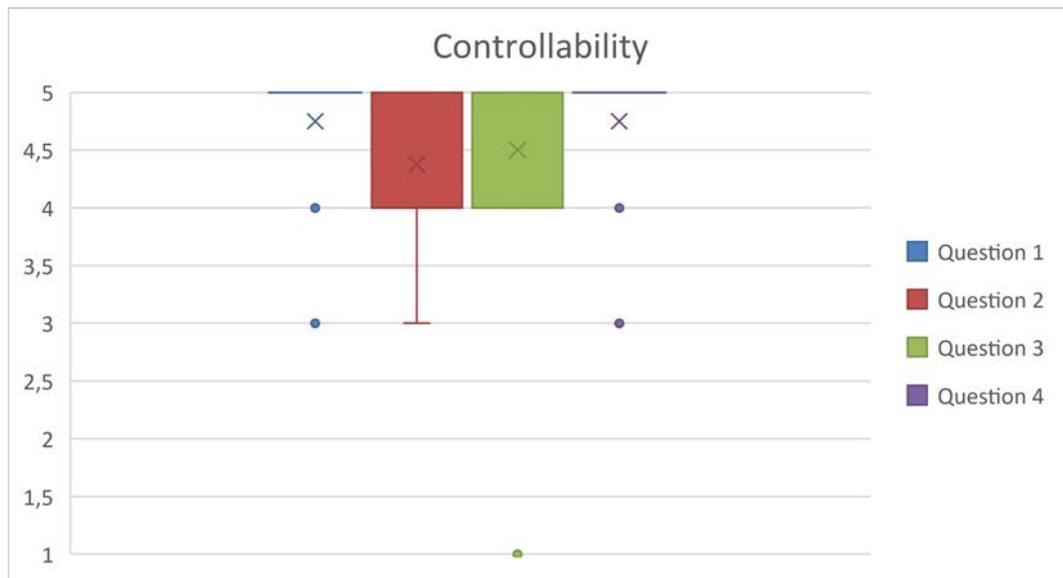


Figure 8 Box plot depicting the results for the question set "controllability"

This question set was one of the most clearly answered sets of the whole questionnaire. Except of some outliers, the answers to the questions, evaluation if the users were able to use the software in a personal way, the answers were mostly positive. The software does not use any safe states. This is because restoring the previous state after quitting the application is a matter of a few clicks. Therefore, the software allows the user to almost pick up their work, where they left (question one). The second question asked if using the software required the user to follow a specific procedure. Only one participant rated the software very bad (one point out of five), stating that the software did not allow the user to customize, where information is visible on the screen. Then again, almost every participant rated the software with five of five points at question four. This question evaluated if the software requires the user to interrupt their workflow because of the application.

4.1.4 Conformity with the user expectation

In the box plot below, one can see that the users did not feel that a common design language was helping them navigate through the application or that the common design language was missing in general (question one). The second question asked if the app was clear about whether an action or input was successfully processed or not. All the participants answered the question with a rating of four or five, stating that the application was very clear about inputs. The participants also felt that the application reacted with foreseeable processing times as it can be seen in the answers on question four. Thirteen people considered the single available gesture to be a uniform principle of using the application. Only three persons did not think so.

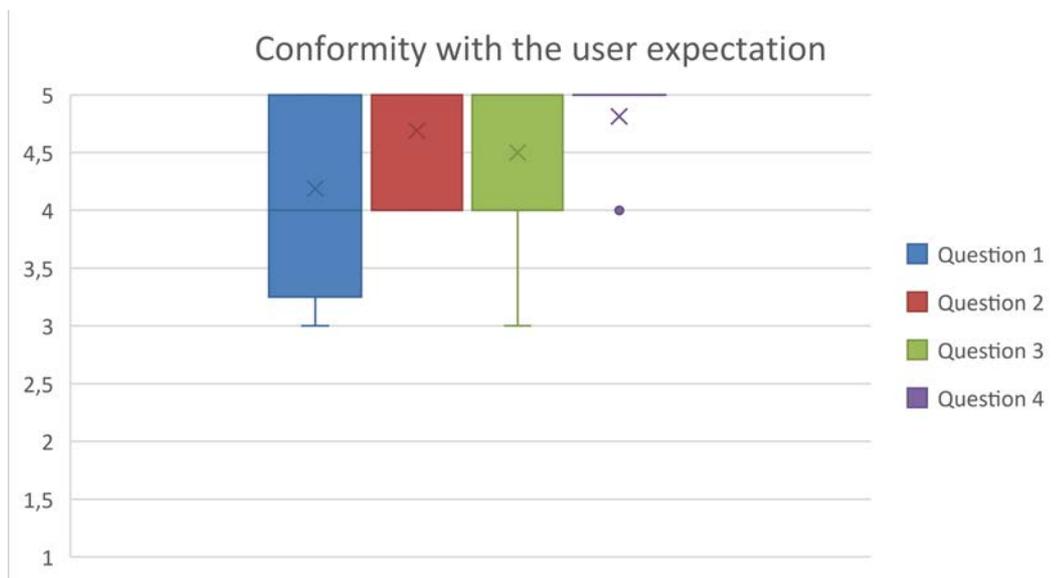


Figure 9 Box plot depicting the results for the question set “Conformity with the user expectation”

4.1.5 Error tolerance

The topic “error tolerance” was not a very controversial one. The ratings of both questions ranged from three upwards. This is generally a positive evaluation. The second question asked if, once an error occurred, it required great effort to correct the consequences of the error. There are two errors that can happen. First, the application can crash. Second, the user could place the virtual hand outside of the room under certain circumstances. Both errors can be corrected by relaunching the application. The first question of this set asked, if a small mistake is likely to result in severe consequences. During the testing, no crash occurred. However, one participant placed the virtual hand outside the gymnastics room. This might be the reason for this evaluation.

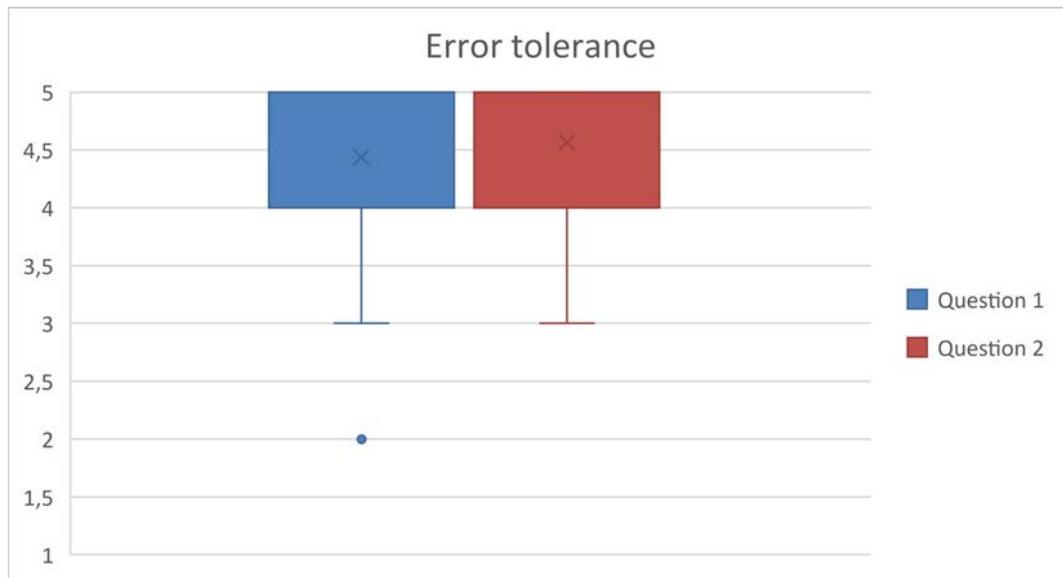


Figure 10 Box plot depicting the results for the question set “Error tolerance”

4.1.6 Suitability for learning



Figure 11 Box plot depicting the results for the question set “Suitability for learning”

Does the software allow to learn how to use the software without great effort and does it help the user to learn new functions of the application? This topic was somewhat controversial. The participants agree that the software does not need much time in order to be learnt how to use it, as it can be seen by looking at the answers of question one. This was one of the goals during the development of the application. The second question asked, if the software encourages users to

try new functions, which not all of the participants think it did. Actually, the ratings scatter from a two-points rating to a five-points rating with most of the answers being three and above. Except for one single participant, the software did not require the users to memorize many details (question three). Looking at the numbers behind question four, one can again see that only one person gave a one-point rating. This question assessed if the software is designed in a way which allows users to memorize details they have once learned. The one-point rating states that this participant felt that the software is not designed that way. Since the software uses a technology not available to the consumer market and therefor not widely used, the results for question five might not surprise the reader. This part of the segment raises the question if the software can be used without help and without a manual. While some users did think that way, some did not.

4.1.7 Individual questions

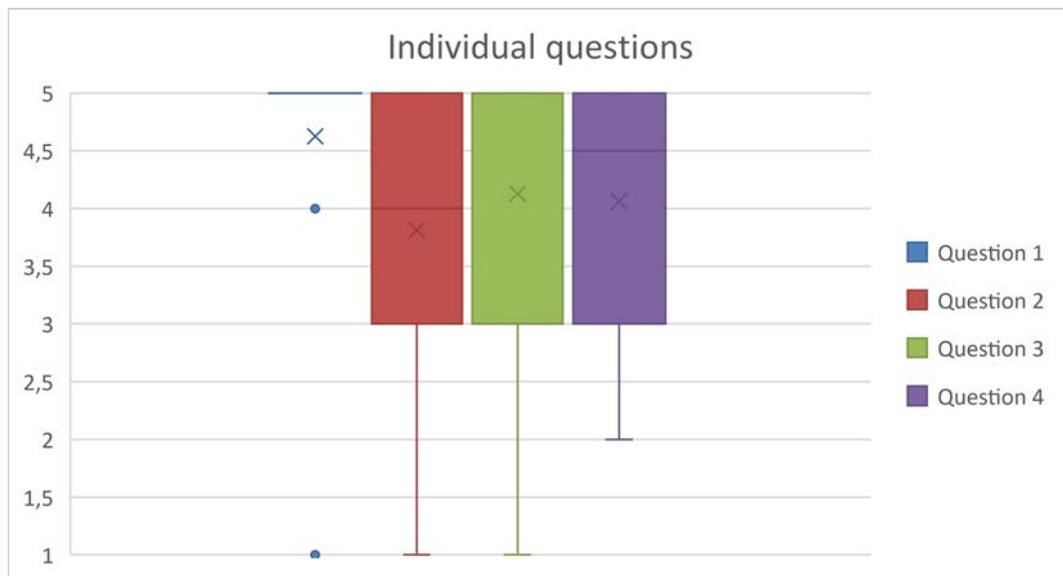


Figure 12 *Box plot depicting the results for the question set "Individual questions"*

The answers to the segment rising individual questions were by far the most controversial ones. Although there were 14 participants stating that the software can help learning anatomical structures, there were still two outliers – one at four points and one at one point. The ratings for questions two and three ranged from one point to five points. Both were about MRI images. The first of those questions (question two) wanted to know whether the visualisation of MRI images with this software was good or bad. By looking closely at the box plot, it is easily visible that the median is below four. While in general the answers to question three

were very similar to the ones rating question two, the median is above four. This question asked if the software was an alternative to MRI images in an educational environment. Lastly, the fourth question evaluated, if the software supports all or none of the possibilities an MRI image supports while learning. While the answers range from two-points to five, the median is closer to five. This means that the majority of the participants felt that the software does support most of the features, an MRI image supports while learning.

4.2 Demographic information

The sixteen participants were equally divided. Eight occupational therapists and eight physiotherapists participated in the study. Two participants were already familiar with Virtual Reality, Augmented Reality or Mixed Reality technology. It was not asked which system or which kind of other reality in particular. Both of those participants were physiotherapists (Table 2).

	Count
Occupational therapists	8
Physiotherapists	8
Participants familiar with AR/VR/MR	2
Participants not familiar with AR/VR/MR	14

Table 2 *Demographic information about the participants*

5 Conclusion and Discussion

5.1 Interpretation

The most unfortunate result of the whole study is, that the software provided is not as self-descriptive as expected. The participants were missing context sensitive information. The information neither showed when the software thought it would be suitable, nor when the users needed them. An easy solution would be to replace the object, depicting the button which rotates the virtual hand and the object representing the world anchor. Some possible alterations would be a steering wheel or a valve wheel as a replacement for the pill. Using the raycast that detects which object the user is looking at in order to also detect the world anchor or the rotation button could also help making the application more self-descriptive. This would of course require some localization as the text shown would have to be translated.

Some users criticized the lack of an overview over the features of the application. While it was considered to be very clear which features are available to the participants during development, the participants themselves thought otherwise. It obviously didn't help that the subjects of the study were told about the feature set of the application before trying it out. Two solutions might come to one's mind right away. One would be to add a tutorial system. This system would go through the features and allow the users to try them out or to read about the functionality. The other solution involves a printed or electronic manual which comes with the software and describes the functions of the software. Both solutions would mean that the user has to learn about the software before learning with the software. A circumstance not embraced by the developer and therefore the solutions were dismissed.

Somewhat controversial were the answers to questions about the conformity with the user's expectations. Those were suggesting that the software did not always go conform with the user's expectations. The participants noted that the design of the application did not always follow the same rules. This could mean that, while rotating the hand with a button, changing the opacity of elements of the hand is done by tapping said elements, confused some participants. Some more development work could change this behavior.

Although the participants saw a lack of self-descriptiveness, they thought that in general, the software was very suitable for learning. However, they did not feel encouraged to try out new functionality. This could also be fixed with a tutorial system, encouraging the users to tap buttons and explore the features of the software provided. Also, some of the participants stated, that without further explanation or a manual, the software was hard to understand. While this might seem like a call for a manual once again, another solution might be more suitable.

One of the most interesting question sets was the individual one. The answers to those questions showed best what the participants liked and disliked about the software. First of all, the participants felt that the software would be able to help students learn about anatomical structures and the relations between them. However, evaluating the answers to the questions also showed that the physiotherapists and occupational therapists did not think that the software would be able to replace MRI images when learning about anatomical structures. This was likely due to the fact that the software did not provide all possibilities, an MRI image provided. One of those features is to see any slice of the MRI image. Also, the participants tended to say that the visualization method used in the software was not suitable for MRI images.

In general, the participants seemed to like the application and the implementation. However, they sometimes felt left alone and maybe overwhelmed with the impressions and possibilities provided by this new technology and this prototype of the application. The software as it is today, seems not appropriate to replace MRI images for educational purposes. It does however, hold great potential.

5.2 Limitations

The software used in this study can be improved rapidly with some minor tweaks. Some other issues must be addressed in the long run. The same is true with this study as a whole. Because of the limited time available to the author some issues could not be addressed during the development phase of the master thesis. Other issues would require the author to meet new agreements and establish new partnerships to solve.

Since the study was held in Vienna, the e-Mail was therefor only sent out to physiotherapists and occupational therapists living in Vienna or the greater metropolitan area including suburbs and surrounding counties. The number of

participants (n=16) was therefore very low. Compensation for the time invested into trying out the software and evaluating the application could increase the number of participants in a further study. Because of the research question, only physiotherapists and occupational therapists were allowed to get involved.

The model used in the study was another somewhat big issue. First of all, it only consisted of parts of the hand. The model was missing the actual fingers and the rest of ulnar and radius. Especially the missing fingers turned out to be a problem while talking to the participants. Obtaining another model would have created the need to establish a new partnership with some entity, providing MRI images. This again is an issue to address in a follow-up study. Maybe this study could even use models of multiple body regions. The model used was created using a two-dimensional process, resulting in an image with anisotropic voxel dimensions. A three-dimensional capture process would have created an image with more isotropic voxel dimensions. This would have created smoother three-dimensional and therefore more realistic models. But again, this could be addressed in a further study on this topic.

The software did not provide enough features, an MRI provides making it hard for the participants to compare the software with MRI images. Also, the participants were not shown the accompanying MRI images with Software like 3D Slicer due to hardware limitations and company policies at the place the study was carried out.

5.3 Outlook

A follow-up study could improve on many aspects of the study carried out during this master thesis. It could not only use better images and an improved software but also newer, improved or even different hardware providing new or refined features. One such device could be the rumored HoloLens 2 which has not been announced yet but is desperately anticipated by many developers around the globe. Peripheral devices such as controllers could further improve the immersiveness of the software and provide a better experience. The software could improve on the variety of models used and also on the model quality. In order to allow a detailed analysis of the benefits of the software it would be wise to implement methods to allow statistical evaluation of the features and the way people interact with the software and the features of the software. The world of technology and medicine is constantly evolving and will most certainly never stop to amaze scientists and users.

Literature

- Barsom, E. Z., Graafland, M., & Schijven, M. P. (2016). Systematic review on the effectiveness of augmented reality applications in medical training. *Surgical Endoscopy*, 30(10), 4174–4183. <https://doi.org/10.1007/s00464-016-4800-6>
- Bernstein, M. A., King, K. F., & Zhou, X. J. (2004). *Handbook of MRI Pulse Sequences*. Elsevier.
- Bredemeyer, H. G., & Bullock, K. (1978). *Orthoptik*. Walter de Gruyter.
- Buchanan, J. A. (2004). Experience with Virtual Reality-Based Technology in Teaching Restorative Dental Procedures. *Journal of Dental Education*, 68(12), 1258–1265.
- D. Fleming, N., & Mills, C. (1992). Not Another Inventory, Rather a Catalyst for Reflection. *To Improve the Academy*, 11. <https://doi.org/10.1002/j.2334-4822.1992.tb00213.x>
- Deyle, G. D. (2011). The role of MRI in musculoskeletal practice: a clinical perspective. *The Journal of Manual & Manipulative Therapy*, 19(3), 152–161. <https://doi.org/10.1179/2042618611Y.0000000009>
- Fiard, G., Selmi, S.-Y., Promayon, E., Vadcard, L., Descotes, J.-L., & Troccaz, J. (2013). Initial validation of a virtual-reality learning environment for prostate biopsies: realism matters! *Journal of Endourology and Part B, Videourology*, 28(4), 453–458. <https://doi.org/10.1089/end.2013.0454>
- Fleming, N. D. (2001). *Teaching and learning styles: VARK strategies* (1st ed). Christchurch, N.Z.: N.D. Fleming. Retrieved from <https://trove.nla.gov.au/version/40055720>

- Hashiman, H., Lisanti, C. J., & Bradley, W. G. (2010). *MRI: The Basics* (Third edition). Philadelphia, PA: LWW.
- Kolb, D. A. (2015). *Experiential Learning: Experience as the Source of Learning and Development*. Pearson Education, Incorporated.
- Marcy, V. (2001). Adult Learning Styles: How the VARK© Learning Style Inventory Can Be Used to Improve Student Learning. *The Journal of Physician Assistant Education*, 12, 117–120.
<https://doi.org/10.1097/01367895-200107000-00007>
- Mildenberger, P., Eichelberg, M., & Martin, E. (2002). Introduction to the DICOM standard. *European Radiology*, 12, 920–927.
<https://doi.org/10.1007/s003300101100>
- Milgram, P., & Kishino, F. (1994). A TAXONOMY OF MIXED REALITY VISUAL DISPLAYS, 15.
- Miller, P. (2001). *Learning Styles: The Multimedia of the Mind. Research Report*. Retrieved from <https://eric.ed.gov/?id=ED451140>
- Norman, G., Dore, K., & Grierson, L. (2012). The minimal relationship between simulation fidelity and transfer of learning. *Medical Education*, 46(7), 636–647. <https://doi.org/10.1111/j.1365-2923.2012.04243.x>
- Othman, N., & Amiruddin, M. H. (2010). Different Perspectives of Learning Styles from VARK Model. *Procedia - Social and Behavioral Sciences*, 7, 652–660. <https://doi.org/10.1016/j.sbspro.2010.10.088>
- Pieper, S., Halle, M., & Kikinis, R. (2004). 3D slicer. In *IEEE International Symposium on Biomedical Imaging: Nano to Macro* (Vol. 1, pp. 632-635 Vol. 1). <https://doi.org/10.1109/ISBI.2004.1398617>
- Prümper, J. (1999). ISONORM 9241-10_Skalenkonstruktion(englisch).pdf. Retrieved March 31, 2018, from [http://people.f3.htw-berlin.de/Professoren/Pruemper/instrumente/ISONORM%209241-10_Skalenkonstruktion\(englisch\).pdf](http://people.f3.htw-berlin.de/Professoren/Pruemper/instrumente/ISONORM%209241-10_Skalenkonstruktion(englisch).pdf)

- Prümper, J., & Anft, M. (1993). Die Evaluation von Software auf Grundlage des Entwurfs zur internationalen Ergonomie-Norm ISO 9241 Teil 10 als Beitrag zur partizipativen Systemgestaltung — ein Fallbeispiel. In *Software-Ergonomie '93* (pp. 145–156). Vieweg+Teubner Verlag, Wiesbaden. https://doi.org/10.1007/978-3-322-82972-6_12
- Richardson, D. (2011). Is virtual reality a useful tool in the teaching of physiology? *Advances in Physiology Education*, 35(2), 117–119. <https://doi.org/10.1152/advan.00002.2011>
- Riecke, B., Bodenheimer, B., P. McNamara, T., Williams, B., Peng, P., & Feuereissen, D. (2010). Do We Need to Walk for Effective Virtual Reality Navigation? Physical Rotations Alone May Suffice (Vol. 6222, pp. 234–247). https://doi.org/10.1007/978-3-642-14749-4_21
- Salehi, S. (2007). Nursing Students' Preferred Learning Styles. *Journal of Medical Education*, 11(3&4). <https://doi.org/10.22037/jme.v11i3&4.1376>
- Sánchez, Á., Barreiro, j. ., & Maojo, V. (2000). Design of Virtual Reality Systems for Education: A Cognitive Approach. *Education and Information Technologies*, 5, 345–362. <https://doi.org/10.1023/A:1012061809603>
- Selvander, M., & Åsman, P. (2012). Virtual reality cataract surgery training: learning curves and concurrent validity. *Acta Ophthalmologica*, 90(5), 412–417. <https://doi.org/10.1111/j.1755-3768.2010.02028.x>
- Sheth, S. S., Fader, A. N., Tergas, A. I., Kushnir, C. L., & Green, I. C. (2014). Virtual Reality Robotic Surgical Simulation: An Analysis of Gynecology Trainees. *Journal of Surgical Education*, 71(1), 125–132. <https://doi.org/10.1016/j.jsurg.2013.06.009>
- Tickoo, O., & Iyer, R. (2016). *Making Sense of Sensors: End-to-End Algorithms and Infrastructure Design from Wearable-Devices to Data Centers*. Apress.

- Wang, Z., Ni, Y., Zhang, Y., Jin, X., Xia, Q., & Wang, H. (2014). Laparoscopic Varicocelelectomy: Virtual Reality Training and Learning Curve. *JSLS: Journal of the Society of Laparoendoscopic Surgeons*, 18(3).
<https://doi.org/10.4293/JSLS.2014.00258>
- Yusoff, R. C. M., Zaman, H. B., & Ahmad, A. (2010). Design A Situated Learning Environment Using Mixed Reality Technology - A Case Study, 4(11), 6.

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Appendix

A. Questionnaire

1	2	3	4	5
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Aufgabenangemessenheit

Die Software...

ist kompliziert zu bedienen						ist unkompliziert zu bedienen
bietet schlechte Möglichkeiten, sich häufig wieder-holende Bearbeitungsvorgänge zu automatisieren.						bietet gute Möglichkeiten, sich häufig wieder-holende Bearbeitungsvorgänge zu automatisieren.
erfordert überflüssige Eingaben.						erfordert keine überflüssigen Eingaben.

Selbstbeschreibungsfähigkeit

Gibt Ihnen die Software genügend Erläuterungen und ist sie in ausreichendem Maße verständlich?

bietet einen schlechten Überblick über ihr Funktionsangebot.						bietet einen guten Überblick über ihr Funktionsangebot.
verwendet schlecht verständliche Begriffe, Bezeichnungen, Abkürzungen oder Symbole in Masken und Menüs.						verwendet gut verständliche Begriffe, Bezeichnungen, Abkürzungen oder Symbole in Masken und Menüs.
liefert in unzureichendem Maße Informationen darüber, welche Eingaben zulässig oder nötig sind.						liefert in zureichendem Maße Informationen darüber, welche Eingaben zulässig oder nötig sind.
bietet auf Verlangen keine situationsspezifischen Erklärungen, die konkret weiterhelfen.						bietet auf Verlangen situationsspezifische Erklärungen, die konkret weiterhelfen.
bietet von sich aus keine situationsspezifischen Erklärungen, die konkret weiterhelfen.						bietet von sich aus situationsspezifische Erklärungen, die konkret weiterhelfen.

Steuerbarkeit

Können Sie als Benutzer die Art und Weise, wie Sie mit der Software arbeiten, beeinflussen?

bietet keine Möglichkeit, die Arbeit an jedem Punkt zu unterbrechen und dort später ohne Verluste wieder weiterzumachen.						bietet die Möglichkeit, die Arbeit an jedem Punkt zu unterbrechen und dort später ohne Verluste wieder
--	--	--	--	--	--	--

						weiterzumachen.
erzwingt eine unnötig starre Einhaltung von Bearbeitungsschritten.						erzwingt keine unnötig starre Einhaltung von Bearbeitungsschritten.
ist so gestaltet, daß der Benutzer nicht beeinflussen kann, wie und welche Informationen am Bildschirm dargeboten werden.						ist so gestaltet, daß der Benutzer beeinflussen kann, wie und welche Informationen am Bildschirm dargeboten werden.
erzwingt unnötige Unterbrechungen der Arbeit.						erzwingt keine unnötigen Unterbrechungen der Arbeit.

Erwartungskonformität

Kommt die Software durch eine einheitliche und verständliche Gestaltung Ihren Erwartungen und Gewohnheiten entgegen?

erschwert die Orientierung, durch eine uneinheitliche Gestaltung.						erleichtert die Orientierung, durch eine uneinheitliche Gestaltung.
läßt einen im Unklaren darüber, ob eine Eingabe erfolgreich war oder nicht.						läßt einen nicht im Unklaren darüber, ob eine Eingabe erfolgreich war oder nicht.
reagiert mit schwer vorhersehbaren Bearbeitungszeiten.						reagiert mit gut vorhersehbaren Bearbeitungszeiten.
läßt sich nicht durchgehend nach einem einheitlichen Prinzip bedienen.						läßt sich durchgehend nach einem einheitlichen Prinzip bedienen.

Fehlertoleranz

Bietet Ihnen die Software die Möglichkeit, trotz fehlerhafter Eingaben das beabsichtigte Arbeitsergebnis ohne oder mit geringem Korrekturaufwand zu erreichen?

ist so gestaltet, daß kleine Fehler schwerwiegende Folgen haben können.						ist so gestaltet, daß kleine Fehler keine schwerwiegenden Folgen haben können.
erfordert bei Fehlern im großen und ganzen einen hohen Korrekturaufwand.						erfordert bei Fehlern im großen und ganzen einen geringen Korrekturaufwand.

Lernförderlichkeit

Ist die Software so gestaltet, daß Sie sich ohne großen Aufwand in sie einarbeiten konnten und bietet sie auch dann Unterstützung, wenn Sie neue Funktionen lernen möchten?

erfordert viel Zeit zum Erlernen.						erfordert wenig Zeit zum Erlernen.
ermutigt nicht dazu, auch neue Funktionen auszuprobieren.						ermutigt dazu, auch neue Funktionen auszuprobieren.
erfordert, daß man sich viele Details merken muß.						erfordert nicht, daß man sich viele Details merken muß.
ist so gestaltet, daß sich einmal Gelerntes schlecht einprägt.						ist so gestaltet, daß sich einmal Gelerntes gut einprägt.

ist schlecht ohne fremde Hilfe oder Handbuch erlernbar.							ist gut ohne fremde Hilfe oder Handbuch erlernbar.
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Individuelle Fragen

Ist die Software so gestaltet, dass sie einem Physiotherapeuten/Ergotherapeuten im vorgesehenen Einsatzbereich nützlich sein kann?

kann beim Lernen von anatomischen Strukturen nicht helfen.						kann beim Lernen von anatomischen Strukturen helfen.
bietet eine schlechte Visualisierung von MRT Daten.						bietet eine gute Visualisierung von MRT Daten.
stellt keine Alternative zu MRT Bildern im Lernsetting dar.						stellt eine Alternative zu MRT Bildern im Lernsetting dar.
unterstützt keine der Möglichkeiten, die ein MRT Bild beim Lernen bietet.						unterstützt alle der Möglichkeiten, die ein MRT Bild beim Lernen bietet.

Zum Schluß

Zum Schluß bitten wir Sie, noch folgende Fragen zu beantworten:

Was ist Ihr Beruf?

Haben Sie schon einmal eine VR/AR/MR-Software verwendet?

B. Results

Suitability for the task					
	1-1	1-2	1-3		
Participant 1	5	5	5		
Participant 2	4	4	4		
Participant 3	5	4	5		
Participant 4	4	4	5		
Participant 5	5	1	5		
Participant 6	3	1	5		
Participant 7	4	5	5		
Participant 8	5	1	5		
Participant 9	5	3	5		
Participant 10	5	3	5		
Participant 11	5	4	5		
Participant 12	5	3	5		
Participant 13	4	3	5		
Participant 14	4	4	4		
Participant 15	3	1	5		
Participant 16	5	4	5		
Self-descriptiveness					
	2-1	2-2	2-3	2-4	2-5
Participant 1	2	5	2	2	2

Participant 2	4	4	3	3	2
Participant 3	2	3	1	1	1
Participant 4	4	5	3	4	3
Participant 5	5	3	4	3	3
Participant 6	2	3	2	1	1
Participant 7	5	5	5	4	5
Participant 8	5	5	1	1	1
Participant 9	4	4	4	2	3
Participant 10	5	5	5	2	1
Participant 11	5	5	1	3	3
Participant 12	5	5	4	1	2
Participant 13	3	4	3	3	4
Participant 14	3	2	3	2	2
Participant 15	3	4	4	2	1
Participant 16	3	5	1	2	1
Controlability					
	3-1	3-2	3-3	3-4	
Participant 1	5	4	5	5	
Participant 2	5	4	5	4	
Participant 3	5	4	4	5	
Participant 4	5	4	5	5	
Participant 5	5	3	5	5	
Participant 6	5	4	4	5	
Participant 7	5	5	5	5	
Participant 8	5	5	5	5	
Participant 9	3	4	4	3	
Participant 10	5	5	5	5	
Participant 11	4	5	5	5	
Participant 12	5	5	5	5	
Participant 13	5	5	5	5	
Participant 14	5	4	1	4	
Participant 15	4	5	5	5	
Participant 16	5	4	4	5	
Conformity with the user expectation					
	4-1	4-2	4-3	4-4	
Participant 1	5	4	4	5	
Participant 2	4	5	4	5	
Participant 3	4	4	5	5	
Participant 4	5	5	4	5	
Participant 5	3	5	5	5	
Participant 6	3	5	5	5	
Participant 7	5	5	5	5	

Participant 8	5	5	5	5	
Participant 9	4	5	5	5	
Participant 10	4	5	3	5	
Participant 11	5	5	4	5	
Participant 12	5	5	5	5	
Participant 13	5	5	4	5	
Participant 14	3	4	5	4	
Participant 15	3	4	5	4	
Participant 16	4	4	4	4	
Error tolerance					
	5-1	5-2			
Participant 1	4	4			
Participant 2	3	3			
Participant 3	4	3			
Participant 4	4	4			
Participant 5	5	5			
Participant 6	2	5			
Participant 7	5	5			
Participant 8	5	5			
Participant 9	5	5			
Participant 10	5	4			
Participant 11	5	5			
Participant 12	5	5			
Participant 13	5	5			
Participant 14	5	5			
Participant 15	5	5			
Participant 16	4	5			
Suitability for learning					
	6-1	6-2	6-3	6-4	6-5
Participant 1	5	3	5	5	2
Participant 2	4	4	4	5	4
Participant 3	5	4	5	4	4
Participant 4	5	4	5	3	5
Participant 5	5	5	5	5	3
Participant 6	4	2	5	1	4
Participant 7	5	5	5	5	5
Participant 8	5	5	5	5	5
Participant 9	5	5	5	5	4
Participant 10	5	5	5	5	4
Participant 11	5	5	1	5	5
Participant 12	5	5	5	5	2
Participant 13	4	4	5	4	4

Participant 14	4	5	4	4	5
Participant 15	4	3	4	4	2
Participant 16	5	3	5	5	2
Individual questions					
	7-1	7-2	7-3	7-4	
Participant 1	5	4	3	3	
Participant 2	5	4	5	4	
Participant 3	4	2	3	3	
Participant 4	4	5	5	5	
Participant 5	5	5	5	5	
Participant 6	1	1	1	3	
Participant 7	5	5	5	5	
Participant 8	5	5	5	5	
Participant 9	5	4	4	5	
Participant 10	5	5	5	5	
Participant 11	5	4	5	4	
Participant 12	5	5	4	5	
Participant 13	5	4	5	4	
Participant 14	5	2	3	2	
Participant 15	5	3	3	2	
Participant 16	5	3	5	5	
Demographic information					
	8-1				8-2
Participant 1	Physio therapist				Yes
Participant 2	Occupational therapist				No
Participant 3	Occupational therapist				No
Participant 4	Occupational therapist				No
Participant 5	Occupational therapist				No
Participant 6	Physio therapist				No
Participant 7	Physio therapist				No
Participant 8	Occupational therapist				No
Participant 9	Occupational therapist				No
Participant 10	Occupational therapist				No
Participant 11	Physio therapist				No
Participant 12	Physio therapist				No
Participant 13	Occupational therapist				No
Participant 14	Physio therapist				Yes
Participant 15	Physio therapist				No
Participant 16	Occupational therapist				No

