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Master Thesis

Student and Teacher Meet in a Shared Virtual Environment: A VR One-on-One Tutoring System to Support Anatomy Education

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Abstract

A Virtual Reality one-on-one tutoring system to support anatomy education is introduced. A student uses the *HTC Vive* as a fully immersive Virtual Reality device to explore the anatomy of the base of the human skull. Connected via network a teacher shares the Virtual Reality experience with the student via the semi-immersive *zSpace*. The teacher is provided with various features to guide the student through the immersive learning experience. He can influence the students navigation or provide annotations on the fly and, hereby, improve the students learning experience.
The system is implemented as a prototype application using the *Unity* game engine. An informal evaluation shows that the one-on-one tutoring approach provides a solid bases for future research in the area of shared virtual environments for anatomy education.

Contents

List of Figures

1. Introduction

The knowledge of anatomical structures and their spacial relations is fundamental for the understanding of medical problems. Therefore, anatomy education is an integral part of the medical curriculum. There is a variety of different methods to teach anatomy, comprising anatomy atlases and dissections as the traditional ones. However, in modern medical classes, constraints of time and resources, such as teaching staff or money, bring up the urge for alternative, more effective teaching tools [SAK10]. Innovative approaches that take advantage of new technologies such as Virtual Reality (VR) devices, already augment the traditional methods of anatomy education.

Virtual Reality devices, such as head-mounted displays (HMD), allow the user to fully immerse in a virtual environment. With position tracking and 3D input devices, such as motion controllers, the user can interact naturally in the virtual world. There are already applications that use this potential for anatomy education, such as the *Cyber Anatomy Room* (see Section 2.1.2). Students can inspect virtual models of the human body and understand spacial relations through freely adjusting the view. They profit from a direct integration of names and descriptions of specific structures, linked to the virtual models – a fully immersive 3D anatomy atlas.

Existing VR applications usually enable the student to freely explore the virtual environment. Although this allows him to learn at an individual pace, he may waste time following unproductive paths or may even miss important details [DHB01]. Guiding a student through a Virtual Reality experience to ensure effective learning, would be an innovative approach. In a *one-on-one tutoring* scenario, a teacher could give instructions on finding a specific structure, intervene if a student took too long navigating, or he may even explain material to the student through dedicated input techniques. However, Virtual Reality applications are usually designed as a one person experience, where no intervention from outside is possible. Specifically when using an HMD, the user's real environment is completely blocked out. Having a 2D application, a teacher could explain something while pointing to a specific location on a display or using additional methods like drawing on a whiteboard. In an immersive Virtual Reality application, however, the teacher also needs to directly interact with the virtual world and join the student in a shared Virtual Reality.

1.1 Goal of this Thesis

This thesis introduces an approach for a Virtual Reality one-on-one tutoring system to support anatomy education. Thereby it shall be answered, how the student's VR learning experience can be improved, when being guided by a teacher in a shared virtual environment. Focussing on *gross anatomy*, the human base of the skull will serve as an application example.

The system shall support a medical student in exploring anatomical data intuitively through a fully immersive VR device. Dedicated input techniques shall be provided to the teacher (a) for the creation of annotations and (b) to help the student navigate to specific locations. The student is provided with the *HTC Vive*, while the teacher uses the semi-immersive *zSpace*. These two devices need be connected via network. The users' positions shall be synchronized, as well as the annotations created by the teacher. The system will be implemented as a prototype using the *Unity* game engine and its integrated multiplayer network support. An evaluation takes place, using both devices in one location. An implementation of synchronized audio input and output, which is required for remote usage, is not part of this work.

1.2 Structure of the Thesis

This thesis comprises the following chapters:

Chapter 2 gives an overview on related work, comprising methods of anatomy education, Virtual Reality with its potential for education and 3D interaction techniques.

Chapter 3 introduces the concept for a VR one-on-one tutoring system by discussing details of the approach. It starts out with an analysis of requirements for both the student's and teacher's system.

Chapter 4 briefly states relevant aspects of the implementation of the prototype. It addresses the VR devices being used as well as the Unity game engine and its integrated network support.

Chapter 5 describes the evaluation process of the implemented prototype and discusses the results.

Chapter 6 gives a concluding summary of the thesis, ending with an outlook on the research that can follow this work.

2. Related Work

The following chapter discusses several research aspects that are relevant for the VR tutoring approach presented in Chapter 3. Starting with the field of anatomy education, Section 2.1 gives an overview on common teaching methods in this field. It focusses on computer-bases learning approaches (Section 2.1.1) and discusses their advantages and disadvantages in comparison to the traditional dissection (Section 2.1.2).
Further, Section 2.2 presents a sensitisation for the field of Virtual Reality. The concept of depth perception (Section 2.2.1) and the differentiation between immersive and semi-immersive systems (Section 2.2.2) is explained. An outline of current VR input and output devices (Section 2.2.3) is given, before the importance of VR as a learning environment (Section 2.2.4) is discussed. It further highlights the concept of shared Virtual Reality (Section 2.2.5) and the potential of Virtual Reality in one-on-one tutoring (Section 2.2.6).
Section 2.3 gives an overview on different 3D interaction techniques. It discusses navigation (Section 2.3.1) and object manipulation (Section 2.3.2) in a virtual environment, as well as menu presentation (Section 2.3.3). The concepts of labelling and sketching as annotations are presented (Section 2.3.4). The chapter closes with a short outline on usability (Section 2.3.5).

2.1 Anatomy Education

Human anatomy is a key aspect in medical education. Medical curricula target the understanding of anatomical structures, their form, position, size and their spacial relationship. An undergraduate medical student needs to acquire a solid understanding of the human body. The scientific study of anatomy covers different fields. Among others it includes *gross anatomy* (the study of the structure and positioning of organs on a macroscopic level), *histology* (the study of microscopic anatomy), or *neuroanatomy* (the study of the brain, spinal cord and peripheral nervous system) [BHB+07]. *Gross anatomy* is an integral part of the medical curriculum and will be the focus of this work.

In [Ros95], Rosse proposes a classification of anatomical information. He distinguishes between two representations. Linking both domains of information, it is easier for a student to develop a cognitive model of the anatomical structures:

Spacial Domain comprises the actual anatomic entities with their shape, size, texture and subdivisions.

Symbolic Domain is the verbal description of the names of anatomic structures, as well as anatomic concepts and relationships, described through written or spoken language.

There are different methods of teaching anatomy, reaching from traditional ones like cadaver dissection, lectures and anatomy atlases to new approaches, enabled through evolving technological possibilities. Focussing on *gross anatomy*, the main teaching method for the past 400 years has been the cadaver dissection [EB16], as it still comes with advantages that computer-based learning methods cannot compete with, as discussed in Section 2.1.2. Another method is the prosection, where the dissection is done by an experienced anatomist for demonstration and the already dissected specimen are then examined by the students. Through plastination, a way of preservation, the prosections can last longer.
A common learning approach are lectures, where knowledge can be efficiently transferred to many students at a time. Extended with the so-called problem-based learning method [Sch83], students research a real-world medical problem individually with given resources, such as textbooks, and afterwards discuss their results in small groups. Textbooks and anatomy atlases help to learn the names and functions of anatomy structures and depict them in 2D graphics to illustrate their spacial relations. Illustrations are labelled, in order to link the spacial and symbolic domain (see Figure 2.1). However, 2D illustrations have its limitations when trying to understand 3D spacial relations of anatomic structures, as students have to switch between several illustrations that show different perspectives.

All traditional methods and new approaches come with their individual advantages and disadvantages. A single teaching tool that meets all curriculum requirements has not been found yet [EB16], which makes a combination of different methods the way to proceed.

2.1.1 Computer-based Learning Approaches

Various computer-based learning approaches already augment the possibilities of anatomy education. There is a range of different applications, comprising medical databases, interactive 3D anatomical atlases or approaches taking advantage of latest technology such as Virtual Reality devices.

The *VOXEL-MAN* [HPP+96] is a pioneer in three-dimensional anatomy teaching (see Figure 2.2)[1] and it provides an interactive 3D representation of human anatomy. The

[1] https://www.voxel-man.com/3d-navigator/ (accessed: 31.05.2017)

Figure 2.1: A labelled 2D illustration showing the internal surface of the bones of the human skull from different perspectives, retrieved from [PP00].

model can be inspected from different angles and virtual dissection can be performed on the 3D virtual anatomy, as parts of the model can be removed. To combine this spacial information with the symbolic domain, each structure is labelled and described. The *VOXEL-MAN* is based on the *Visible Human dataset* [ASSW94], a 3D dataset created from two bodies that where given to science and digitized. This dataset is frequently used for a variety of computer-based medical applications.

Another example is the *Zoom Illustrator* [PRS97]. It uses sophisticated methods to label 3D objects that are examined through free view adjustment, scaling and rotation. Approaches like this or the *VOXEL-MAN* are oriented towards an atlas metaphor. An evaluation of interaction techniques for the exploration of 3D illustrations [PPS99] showed that students would appreciate to have more freedom in interacting with a 3D anatomy model, like assembling structures themselves. Motivated by this, a 3D puzzle metaphor for learning spacial relations was introduced in [RPDS00]. This 3D puzzle of anatomic structures adds a gaming component to the learning of spacial relations of anatomy.

The presented examples use 2D input- and output devices, which can be challenging when examining 3D structures. Virtual Reality devices enable to interact with 3D virtual anatomy models in an immersive and natural way. *Cyber Science 3D*[2] already provides immersive applications for the exploration of human anatomy that are used in medical education. They are targeting the semi-immersive *zSpace* (see Section 4.1.2) and offer a fully immersive *CAVE* experience (Figure 2.3)[2] (see Section 2.2.3 for VR

[2] http://cyberscience3d.com/ (accessed: 31.05.2017)

Figure 2.2: The user interface of the *VOXEL-MAN 3D Navigator*

devices). The 3D anatomy data can be explored in full freedom and a virtual dissection mode is offered.

2.1.2 Cadaver Dissection vs. Computer-based Learning

Cadaver dissection as the traditional method is still the common way to teach anatomy. However, discussion arises if full cadaver dissection is still suitable [EB16]. The availability of cadavers is limited and decreasing. Due to rising costs, many medical schools do not include cadaver dissection labs any more [NCFD06]. The highly time-consuming procedure is not suitable for large medical classes and working with a cadaver is potentially hazardous. Prosections are helping, as they reduce time to find relevant structures. When preserving body parts through plastination, several students can work on the specimen over a longer timespan. This approach, however, also has its limitations. Such treated parts are affected by shrinkage and may lose their texture and color over time [EB16].

Further, dissection is an ineffective method for very complex structures, e.g., the middle and inner ear [NCFD06]. To expose anatomical structures of such a small size requires advanced dissection skills, but usually medical students lack these. Artificial physical

Figure 2.3: The *Cyber Anatomy Room*: A user wears tracked glasses that enable him to have a stereoscopic view of the 3D scene that is projected onto walls. The image is distorted according to the tracked position of the user.

models as an alternative are, however, highly priced and significant anatomical details may be absent.

Computer-based learning methods try to overcome these challenges. Already in the year 1967, Starkweather saw the potential of computer-based learning [Sta67]. He highlights, that computers with their adaptive feedback and dynamic response let the students explore medical problems at their own pace. While anatomical structures and their spacial relations may be destroyed during a dissection, before even identifying them, computer-based techniques allow a richer appreciation of the three-dimensional quality of the anatomy [Ros95]. Students are able to repeatedly dissect anatomic structures virtually and reconstruct areas. Structures can be examined in ways that are not possible in real life, like scaling them or modifying the opacity of certain areas [HV97].

Following Rosse's definition of the two different representations of anatomical information ([Ros95] and Section 2.1), traditional methods clearly separate these. Dissections expose the actual anatomic structures, thus, explore the spacial domain. The symbolic domain is mainly represented through lists of terms, e.g. in textbooks. This separation makes it hard to develop a cognitive model to link spacial and symbolic information. Computer-based methods provide the possibility to link the two domains, by directly incorporating symbolic information into the presentation of anatomic models. The representation of virtual anatomical models allows an autonomous exploration where detailed structures are easily accessible through adjusting views and angles. The anatomic structures can additionally be augmented with information in various forms, such as text, images, sound, video or interactive modules.

Compared to dissection, the exploration of virtual anatomical models is a cost-effective alternative. Despite overcoming various problems of traditional methods, computer-based approaches are not meant to fully replace them. Cadaver dissection prepares students for clinical practice and especially the encounter with death [SAK10][EB16]. In this respect, a simulation is no replacement for the real world. Computer-based methods, however, are a powerful tool to augment and enhance other teaching strategies.

2.2 Virtual Reality

According to [SC02], there are four aspects of Virtual Reality that can be distinguished. The *virtual world* itself is an imaginary space - the content presented through a medium. In the application of anatomy, for example, the content may comprise anatomy structures represented as virtual objects.
Another aspect is *immersion*, which can be divided into physical- and mental immersion [SC02]. While mental immersion is the sensation of being deeply engaged in an environment through involvement, physical immersion refers to the body's senses that are stimulated through the Virtual Reality system.
This physical immersion can be induced by *sensory feedback*. Through sensory feedback Virtual Reality approaches the physical reality of the real world. Besides visible feedback, haptic feedback can be realised with special devices, like controllers with vibrotactile feedback. Tracking systems play a great role in order to base the sensory output on the users position.
Interactivity, meaning that the system responds to the user's action, makes the virtual reality authentic. This can be the changing of one's viewport or the ability to affect the virtual world.
Not every one of these aspects has to be equally considered for a Virtual Reality application. Weighting one over the other may be useful regarding the application scenario [HRL10].

2.2.1 Depth Perception

The human *field of view*, the width of the currently visible environment, is approximately 200°. There is a binocular overlap, where both eyes see the environment. This area is the most crucial part and has a width of around 120°. To achieve full immersion, a display with a 120° field of view is generally considered sufficient [MNB14].

Due to the position of both eyes of a human, there is a *binocular disparity* between the two received images. The interpretation of their displacement as depth information is called *stereopsis* [BGG03]. This concept does not work on two-dimensional representations on normal displays. Instead, several depth cues, such as *interposition*, *shading* or *linear perspective*, help to interpret the image regarding depth [SC02].

Virtual Reality devices use certain methods to generate a stereoscopic image. Two images with *binocular disparity* need to be displayed, one for each eye. The *zSpace* as an example for a stereoscopic display (see Section 4.1.2), displays both images superimposed with different polarizing filters. The user wears passive polarized glasses. This way, each eye has a different polarizing filter to see only one of the images. HMDs such as the *HTC Vive* (see Section 4.1.1) display both images side by side. Looking through lenses, each eye only sees the one image on their respective side.

2.2.2 Immersive and Semi-immersive Systems

There are different types of systems to present a virtual world through providing sensory feedback. They can be characterized according to their degree of immersion [HV97].
Following the definition of immersion given above, a system that does not alter the sensation of reality can be described as non-immersive. This applies to the standard set-up of a desktop computer with a two-dimensional display. The user can experience the virtual world visually and may interact, but it lacks physical immersion and a sense of presence can hardly be achieved.
A fully immersive system allows physical- and mental immersion. Devices like HMDs completely alter the visual sensation and provide feedback through head-tracking. Some systems allow deep immersion through various sensory feedback, like position-tracking of the body or motion-controllers for hand gestures.
There are systems that settle somewhere between these two. Neither being considered immersive, nor non-immersive, some systems present a virtual world while affecting several senses, but do not provide a complete immersion. Three-dimensional stereoscopic displays coupled with head-tracking, like the *zSpace* (see Section 4.1.2), are an example for such a semi-immersive system. This setup is also called *Fish Tank VR* [WAB93].

While semi-immersive systems lack the power of full immersion, as they constrain the stereopsis to the frontal visual field, they have significant advantages that make them the better choice for certain applications [WAB93]. A semi-immersive system allows the user to still be aware of his surrounding. Thus, it is easier to integrate them in an everyday workspace. Fully immersive systems like HMDs, on the contrary, involve the danger of injuries, as they block out the real world, and may cause a strong feel of exhaustion after extensive use. While HMDs prevent interaction with the real world, semi-immersive systems can be an augmentation to other activities. Further, the resolution is of high importance for HMDs, as their display is placed very close to the eyes - a challenge that semi-immersive systems avoid.

2.2.3 Current Devices

There are several head-mounted displays on the market to experience fully immersive Virtual Reality. Originating from the computer games industry, the popular *Oculus Rift* was a big crowdfunding success on *Kickstarter* in 2012 [3]. Following the *Oculus Rift*, another HMD was released that already comes with a sophisticated tracking system - the *HTC Vive*. Infrared sensors enable room-scale tracking and two motion-controllers provide a variety of input possibilities. Further specifications of the *HTC Vive* are described in Section 4.1.1.
Both devices are available for the consumer to use them with a computer that is equipped with sufficiently strong hardware. Further, there is the *PlayStation VR* headset as an exclusive Virtual Reality device for the PlayStation 4. Thus, it is targeting the game market. It works together with the *PlayStation Move* motion-controllers. These

[3] http://www.bbc.com/news/technology-19085967 (accessed: 31.05.2017)

high-end devices currently do not work wireless yet, but this is surely the next step, as wires can hinder free movement drastically.

While motion-controllers are a common input device for immersive Virtual Reality, there is another approach. The *Leap Motion* tracks hand and finger motions as input and can be used with devices like the *HTC Vive* or *Oculus Rift*. Through gesture input the *Leap Motion* provides a natural user interface.

Opposed to the high-end devices, there are solutions for a mobile Virtual Reality experience that make use of smartphones. A simple version is the *Google Cardboard*. It is basically an enclosure for a smartphone, with lenses to achieve stereopsis. Head-tracking relies on the gyrosensors of the smartphone. Many of these mobile systems lack proper options for input. Often applications rely solely on a gaze-based input, where a focussed interactive element is triggered after a certain time. The *Samsung Gear VR* is a mobile headset for smartphones that has additional sensors to enhance rotation tracking and provides a touch-input field. In addition to the lack of sophisticated input options, these mobile Virtual Reality systems cannot compete with the high-end devices in performance and tracking accuracy.

Head-mounted displays are the common form of immersive Virtual Reality systems. A different approach was introduced in 1992. A system called *CAVE* (CAVE Automtic Virtual Environment) [CNSD93] is a projection-based immersive system - a first step towards Star Trek's holodeck. Images are projected onto the walls of a room-sized cube. Stereopsis is achieved through *LCD shutter glasses* and tracking of the user. A resent example of a similar application is *RoomAlive* [JSM+14]. Unlike HMDs, there is no heavy equipment worn on the head. Thus, it can be used for a longer timespan before exhaustion. Further, the user can see himself inside the virtual environment, thus, no avatar is needed. However, such a system will not find its way into the homes of users as easy as the convenient HMDs do.

The *zSpace* is a semi-immersive Virtual Reality system that matches the definition of *Fish Tank VR* [WAB93]. This stereoscopic display uses a stylus as input device. A further description of the *zSpace* with its technical specifications is given in Section 4.1.2.

2.2.4 Virtual Reality as a Learning Environment

In 1990, Bricken [Bri90] pointed out that the characteristics of Virtual Reality are the same as those of good teaching. A teacher wants to create an environment that is programmable, meaning a curriculum as a planned sequence of instruction, which the students participate in. Virtual Reality augments learning with experience and replaces the desktop metaphor with a world metaphor [Pso95].
In [RSM92] it is stated that VR interfaces are more motivating than traditional 2D interfaces. There is a certain excitement over the use of new technologies [Pso95]. This can be used to make learning more interesting and fun, which may make students remain engaged in learning for a longer period of time. The immersion of Virtual Reality systems is seen as a strong benefit and educators from different fields become increasingly interested in taking advantage of VR technology [HS08].

Previous research [RSM92, RJSM93] showed that it is indeed possible to learn to perform certain tasks in a virtual environment and to transfer this knowledge into the real world. Based on this, simulations as a risk-free training method already exist, e.g., in the fields of military or surgery.

Virtual Reality technology has already been successfully integrated in educational applications [HRL10]. An example for such a Virtual Reality learning environment in the field of anatomy education is *Cyber Science 3D*, mentioned in Section 2.1.1. Such VR applications profit from the natural and intuitive way in which users can interact with the virtual environment. As the cognitive effort is reduced, compared to non-immersive systems, users can fully focus on the scenario rather than on the semantics of the interface [Pso95, HV97].

Usually, Virtual Reality systems for education are based on free-choice learning and discovery [TN02]. Following a museum metaphor, users are often encouraged to stroll around the virtual world and inspect details further, according to personal interest. This way, they will remember general things and random details, instead of global concepts and overarching principles [TN02]. Important learning material may be missed, and moreover, it can be very time-consuming when the user follows unproductive paths [DHB01]. Since VR systems often aim to support or even replace traditional education methods, this pure exploration approach is not suitable, as the learning outcome is unpredictable. To ensure that all important facts are covered, at least a partly prescribed course is needed. A way to achieve this is to let the teacher engage in the virtual environment and guide the student to ensure efficient learning (see Section 2.2.6).

Virtual Reality systems as a learning environment provide benefits through their immersive nature, they are hard to integrate in classroom settings with multiple students. The special hardware that is needed, such as HMDs and motion controllers, are still expensive [TN02, HRL10]. They need sufficient space and can cause sickness and fatique (see also Section 2.3.1). Exhaustion may occur due to the heavy device worn on the head and if a lot of actual physical moving is involved. These factors can inhibit learning and, thus, need to be considered when developing a Virtual Reality learning environment. Thus, mobile devices as a cheaper alternative may be promising for a classroom setting.

2.2.5 Shared Virtual Reality

Existing immersive Virtual Reality applications usually provide a one person experience. However, letting people share a Virtual Reality experience has huge potential. Multiple users are connected through a network and information like object positions will be synchronized. For such an approach, network performance is crucial, as good graphics and low latency is required [Bro00].
In [Bro00] the potential of shared Virtual Reality for education is outlined. The VR technology enables new opportunities to bring together students and teachers from remote places at any time. It can provide access to education everywhere, circumventing problems that the isolation of distance learning usually brings [BPT01]. It raises new

possibilities for explanation and guidance, as educators can lurk over the shoulders of students and intervene [Pso95].

Previous studies show that a collaboration between multiple learners in a shared immersive virtual environment can have a positive educational effect [JTW99, MJOG99, JF00]. The *NICE Project* [JRL+98] is an early example of a collaborative immersive VR learning environment. It is targeted towards children and uses the *CAVE* (Section 2.2.3) as an immersive VR device. Considerable is the representation of the remote users through avatars that mimic the movement of the user, comprising head movement and gestures. This supports the sense of presence and, thus, immersion.
However, the influence of a teacher being present in a shared virtual environment is mainly unevaluated [TN02], even though it is likely to have a positive effect on learning. As stated in Section 2.2.4, a free-choice learning approach, where the student explores the environment freely, has disadvantages. Letting a teacher share the virtual experience for guiding the student, may be beneficial.

Different scenarios for a shared Virtual Reality application can be classified, according to the relationship between the users. In a symmetric setting, each user is an instance with equal conditions. They have the same capabilities when interacting with the system. Opposed to this, an asymmetric setting provides each user with different interaction possibilities. Through unique perspectives, each user contributes to the virtual world in his individual way, according to the advantages of the given interactions. Most collaboration examples of multiple students interacting in one shared virtual environment are symmetric approaches.

An example for an asymmetric setting can be found in [LCDL+16]. The idea of this approach is to perform a 3D manipulation task collaboratively, while the users have a different view on the scene and different manipulation possibilities. One user has an observer view point. Using the semi-immersive *zSpace* (Section 4.1.2), he can perform manipulation tasks from a distance. A second user is placed inside the manipulatable object. Having a detailed view, he can perform precise interactions wearing the *Oculus Rift* and using 3D tracked motion controllers. Additional users are optional. They can switch between different viewpoints as a spectator and give oral instructions.
This approach can be transferred to an education scenario: A teacher may have the global view to supervise a student, while the student has a more detailed view through an immersive device (see also Section 2.2.6). The optional spectators equal a classroom scenario, where other students can observe the interactions.

In [LC03] a whiteboard metaphor is introduced for sharing information between multiple users in a virtual environment. Compared with a classroom, the teacher uses a whiteboard to write down information for the students to learn. This concept can be transported to the virtual world. Sketches can illustrate ideas or concepts and are an effective way of communication in a shared virtual environment. There are also pen-based input devices like the *zSpace* that use a tracked stylus for 3D input, what could be a convenient input device for sketching.

2.2.6 One-on-One Tutoring in Virtual Reality

Tutoring describes a one-on-one dialogue between a teacher and a student with the purpose of helping the student to learn something [EM06]. Bloom showed in 1984 [Blo84] that tutoring is a very powerful tool of instruction. Compared to other methods like group instruction, tutoring is a much more effective way of learning. Despite the great learning success through one-on-one tutoring, it is not always applicable, due to high costs or the number of needed instructors. Computers can support one-on-one tutoring, delivering learning material appropriate for individual needs at "any time, any place, any pace" [DHB01]. Intelligent tutoring systems, where an AI takes over the part of the tutor, are a huge research area in itself.
It is proven that natural language dialogue is very important to tutoring [EM06]. Even though intelligent tutoring systems try to cope with this, one-on-one tutoring by humans is still worthwhile.

Designing a one-on-one tutoring system for a Virtual Reality application comes with challenges. Assuming that the student uses an HMD, in order to profit from the advantages of full immersion, the teacher will not be able to intervene, as the student's real world is completely blocked out by the device. Thus, pointing out details on a display or drawing on a whiteboard are no option. The teacher has to directly interact with the virtual environment, too. Therefore, he also needs a VR device to join the student in a shared Virtual Reality.

2.3 Interacting in a Virtual Environment

While input and output devices (Section 2.2.3) are an important aspect in human-computer-interaction, a huge topic in the research of 3D user interfaces is the design of 3D interaction techniques. Interaction techniques are methods used to accomplish a given task via the interface. Bowman differentiates between so-called *universal 3D tasks* [BKLJP04] :

Navigation is the movement in an environment and comprises *travel* and *wayfinding* (see Section 2.3.1).

Selection and Manipulation are two closely related tasks. With *selection* a specific object among all others is acquired, while *manipulation* further comprises positioning and rotating an object (see Section 2.3.2).

System Control describes sending commands to an application, changing a mode or parameter (see Section 2.3.3).

Symbolic Input lets the user communicate symbolic information to the system. Examples are text input or sketching (Section 2.3.4).

While most of these tasks are intensely researched, the *symbolic input* is rarely present in studies for 3D interfaces. Efficient techniques for this task are difficult to design and to implement [BKLJP04]. Text input for fully immersive VR systems demonstrates this problem. As the user's real-world environment is totally blocked out and usually a surface is not available, as the user moves around, there is no easy way to let him use a keyboard. Often there is only symbolic output present.

There are many different techniques to implement the interaction tasks. Mine [Min95] pointed out three major categories of user control. Individual interaction scenarios might use a combination of controls from each category, keeping in mind their particular benefits and challenges:

Direct User Interaction comprises user action that is directly mapped to the virtual world. Tracking of the user's natural movements, such as pointing or gaze direction, allow intuitive interaction.

Physical Controls are those that exist in the real world, such as buttons on a controller or a joystick. Even though they are more precise to use than *virtual controls*, they may be hard to find in fully immersive settings where the real world is completely blocked out.

Virtual Controls allow a great variety of different controls, as anything is possible in the virtual environment. A virtual button for example, does, however, lack haptic feedback. Virtual controls need to be designed properly, for a precise and intuitive interaction.

While 3D interaction techniques have been widely studied, they still lack in usability [BCW+06] (see Section 2.3.5 for a definition of usability). Thus, research on this topic and the development of new techniques is still relevant. The following sections give an overview on the concept of navigation techniques, selection and manipulation techniques, and talk about labels and sketched annotations as symbolic in- and output.

2.3.1 Navigation

Navigation is often a secondary task in a virtual environment. The focus generally lies on a more important task such as manipulating an object. Thus, navigation techniques need to be intuitive and easy to be controlled, without distracting from other tasks. Navigating in a virtual environment comprises the two aspects *travel* and *wayfinding* [BKLJP04].

Travel

Travel is the motor component – the actions the user makes to change position and orientation. Researchers have introduced several taxonomies to classify the variety of different travel techniques. Bowman et al. [BDHB99] present one that decomposes travel into chronological subtasks (see Figure 2.4). Between starting and stopping the movement, a position and orientation are indicated. There are different possibilities to specify a target position. Either one selects the goal and the system moves the user there in some way, or the user is constantly steering, so the goal position is continuously re-evaluated through the direction of motion. Further, movement along a defined route is possible.

Figure 2.4: Subtasks of a travel technique, taken from [BKLJP04]

The simplest travel technique is to use *direct user interaction*, in order to map physical body movement to the virtual world. The tracking of real movement, such as walking, will initiate a corresponding movement in the virtual environment [Min95]. However, virtual worlds are often larger than the available space in the real world. To still be able to reach distant locations, sophisticated techniques are needed, to map other actions to travelling in the virtual space. Real walking, however, allows a greater sense of immersion, compared to virtual walking or flying [UAW+99].
If real walking is involved and the user's sight is blocked by an HMD, it is necessary to visualize the available real-world space in the virtual environment. A barrier could be shown to prevent the user from colliding with walls or objects, as in [CMRCL09]. Following a flying carpet metaphor, [FCD+10] introduces an approach for an *Immersive Interactive Virtual Cabin*. Integrating the user's motion workspace in the virtual world can also be helpful for multi-user applications [FBHH99], as other users can see what objects lie within range of each user.

Travelling the virtual environment can be done either for *exploration*, as a *search* task or for *manoeuvring*. Without a specific goal in mind, the user might explore the virtual world in order to obtain information about objects and their location. This can help to build a *cognitive map* for wayfinding. Searching something in the virtual environment is a goal-directed techniques. It involves travelling to a specific target location, where acquired spacial knowledge is used for wayfinding. If the user wants to inspect a detail closely, he only needs to navigate precisely within a small area and manoeuvring around the specific region. [BKLJP04]

Wayfinding

Wayfinding is the cognitive component, involving spacial understanding to determine the current location and planning a path to a goal location. In large virtual environments, the extra freedom that sophisticated travel techniques entail can disorient people easily. If the user does not know where to go, travel techniques are not sufficient. *Wayfinding* techniques need to help. Through accessing or acquiring new spacial knowledge, a *cognitive map* of the virtual environment can be build up. Among others, *landmarks* as visually prominent objects are useful. They should stand out from the environment by color and form [BKLJP04]. Stoakley et al. [SCP95] introduces a *World in Miniature* metaphor that offers a hand-held miniature copy of the virtual environment, as a tool to support wayfinding. Generally, wayfinding aids can be included as part of the interface or the environment.

Cybersickness

Travelling in a virtual environment can cause symptoms of classical motion sickness. While motion sickness usually occurs when passively moving, like in a vehicle, cybersickness emerges while the person affected is stationary and only senses motion visually through moving images. This illusion of self-motion is called *vection* [KRHC15]. Symptoms like headache, sweating, nausea and even vomiting characterize cybersickness. However, researches about causing factors are still largely theory, without proof how to circumvent the problem [LJ00]. One old and most accepted theory is the so-called *sensory rearrangement theory*, based on the conflict between the senses that provide information about the body's orientation and motion or a discrepancy to what is expected from previous experience [RB75].
Users are affected by cybersickness to a variable extent. While the reason for this is not known, it was determined that gender, age difference or illness can have an influence, with younger people and women being more susceptible. Further, technical issues like position tracker errors, lag and flicker can have an influence and can evoke cybersickness [LJ00].
There are approaches that try to reduce cybersickness. One example addresses the theory of sensory conflict and proposes to add a motion platform as a visual cue for orientation. However, experiments could not attest its value, as people still got sick [LJ00]. Hopes are high, that future research approaches this problem and make VR experiences enjoyable for anyone.

2.3.2 Object Manipulation

The manipulation of an object in a virtual environment is a fundamental aspect of 3D interaction. Manipulation techniques are a basis for many other interaction techniques. Basic manipulation tasks can be categorized as follows:

Selection is used to identify or acquire a particular object within the entire set of available objects.

Positioning means to change the 3D position of an object, thus, moving an object from an initial location to a target location.

Rotation describes changing the orientation of an object along its axes.

Scaling can be performed uniformly to preserve relations or on a single axis, which results in deformation of the object.

Bowman et al. [BKLJP04] only include the first three tasks, while Mines categorization [Min95] also comprises scaling as a basic manipulation task. To exclude scaling is argued on the fact, that 3D deformation is often done through handles that need selection and positioning tasks to interact with in the first place. Thus, Bowman et al. see scaling as a combination of the other manipulation tasks, rather than a basic one. Very complex manipulation techniques can be developed by a combination of these basic tasks.
Analogous to the taxonomy of navigation tasks in Section 2.3.1, manipulation tasks can also be decomposed into subtasks [BH99]. Figure 2.5 distinguishes between selection, manipulation and release. An object that going to be manipulated through positioning or scaling needs to be indicated first through selection. Releasing a manipulated object terminates a manipulation task.

For manipulation tasks the number degrees of freedom (DOF) of the input device is crucial. Best suitable are 6-DOF devices, as they allow natural control over all input dimensions and, thus, a direct mapping of real-world movements to the virtual environment. This also benefits the sense of immersion.

Selection

A simple way of selection is the *virtual hand* metaphor [PIWB98]. A virtual representation of the user's hand is displayed and moves according to the real-world actions. Objects are selected by *touching* them with the virtual hand. This technique alone does not provide access to remote objects, outside the user's reach. Coupling this approach with navigation techniques is a possible solution. Further, there are already dedicated techniques that allow distant selection.

Two kinds of methods for interacting with remote objects can be classified [BH97][PIWB98]: *Arm-extension* techniques are an enhancement on the virtual hand approach. The *Go-Go* technique [PBWI96] is a prominent example. Further, a variety of *ray-casting*, or *virtual pointer*, techniques enable the user to select objects that are out of his reach. Based on the concept of [Rot82], a virtual ray that stretches out from the user's hand is tested on intersections with objects in the virtual world. Corresponding to a laser pointer metaphor, users find the ray-casting technique easy to understand [Min95]. The evaluation of [PIWB98] shows, that there is no superior method out of the two approaches. [BH99] indicate, that users favour ray-casting over arm-extension for selection tasks, due to the finite reach of the latter .

Moreover, there are several approaches that refine ray-casting, such as the *flexible pointer* [Fei03], or the *bent pick ray* [RHWF06] to circumvent the problem of ray-casting against obscured objects.

Manipulation

The positioning and rotation tasks for a virtual object show a similar decomposition of subtasks and, thus, are discussed in a general fashion under the term *manipulation* (see Figure 2.5 for the decomposition). Usually, manipulation techniques are constructed on top of the selection techniques discussed above, as a selection of a specific object precedes the manipulation of said object. Corresponding to the *virtual hand* metaphor, the object is simply attached to the hand and is manipulated directly. This is the most natural form of manipulation, as the real-world actions are directly mapped to the virtual environment. If objects are attached to a virtual ray, following ray-casting selection technique, the manipulation is less natural.
Reversed to the selection techniques, users prefer arm-extension methods for manipulation [BH99]. That is why [BH97] introduces a combination of both techniques, using ray-casting for selection and arm-extension for manipulation: With the so-called *HOMER* (Hand-centered Object Manipulation Extending Ray-casting) technique, the user selects the object with the ray, but it does not get attached there. The virtual hand move towards the object for attaching it there. When the object is released, the hand returns to its normal position.

The so far mentioned techniques all follow an *egocentric* metaphor, where the user interacts from inside the environment. In contrast, there are *exocentric* techniques, the user has a global view and interacts form outside [PIWB98]. The *World in Miniature* metaphor [SCP95], as an example for an exocentric technique, was already mentioned in the navigation section (Section 2.3.1), as a means of supporting wayfinding.

2.3.3 Menu Presentation

Bowman et al. [BKLJP04] define *system control* as one of the basic 3D tasks. It refers to user interface elements that allow requesting particular functions of the system, changing a mode of interaction or changing the system state. The most popular example of system control in 2D UIs is the WIMP (Windows, Icons, Menus, Pointers) metaphor [MN90]. It provides several techniques, such as pop-up menus, toolboxes, palettes, toggles, radio buttons or checkboxes. However, these concepts cannot simply be adapted for 3D UIs. How user interface elements are displayed is an important aspect for usability (Section 2.3.5). For 3D UIs there are different ways how interface elements are displayed. [KKP+00] distiguishes three possibilities:

World Fixed GUI elements have a static world position. Thus, the user needs to navigate towards such GUI elements. They may be occluded by the virtual world.

View Fixed GUI elements stay at a fixed position and orientation within the user's view and move with the user. As such GUI elements may occlude the virtual world, applying semi-transparency is useful.

Object Fixed GUI elements are attached to a specific object, or to several objects of the same instance, and move with them.

In [SBLJM13] 3D UIs that follow the above categorization are analysed. For a global system control interface they propose a *view fixed* UI. Further, they highlight the importance of attachment. Floating GUIs are said to appear abstract and unnatural in stereoscopic vision. Thus, attaching the elements to the screen frame is recommended. Moreover, an attachment to the bottom of the screen is a preferred placement for usability. To prevent the interface from occluding important parts of the virtual world, a semi-transparent background should be used.

2.3.4 Annotations

Symbolic input as one of the basic 3D tasks, categorized by Bowman et al. [BKLJP04], comprises adding annotations to the virtual world. Annotation techniques are for example *labelling* a specific object or *pen-based* sketching.

Labelling

Labelling is a way to link spacial and symbolic domain (see Section 2.1). Thus, it provides further information about a related object in textual form. The standard input device for textual information is, of course, the keyboard. However, using a keyboard together with immersive VR systems is challenging. In a fully immersive VR experience the user often stands and moves around. There is usually no surface to place the keyboard on. Further, it is not possible to see the keyboard when wearing an HMD. However, using a keyboard with semi-immersive devices such as the *zSpace* (Section 4.1.2) is applicable, as none of the above mentioned problems apply.

Looking at labelled 2D illustrations as a reference (e.g. Figure 2.1), the textual information mostly consist of a small number of words, such as a name. A line is drawn between the textual information and the corresponding part of the spacial domain. An extensive description is not given within a label, due to space limitations. Such information is usually found in texts below an illustration. Interactive systems, however, are able to directly link further information such as detailed descriptions to the label.

Several techniques have been proposed on how to position labels automatically in a 3D environment [PRS97][MTM+16]. In contrast, [SGP15] focuses on enabling the user to interactively create labels. Interaction techniques where developed on creating, repositioning, swapping and deleting labels in immersive and semi-immersive environments. A ray-casting technique is used to define the position of the label on creation. A created label can be dragged to reposition it. The concept was presented in the context of supporting to learn medical structures.

Sketched Annotations

Apart from textual symbolic input through a keyboard, there are also *pen-based* symbolic input techniques that allow adding annotations to the virtual world. These comprise the *unrecognized pen input*, also called *digital ink* [BKLJP04]. An example is to simply draw strokes with a pen-based device, as a natural input for symbols. This can be a convenient technique for communication in a multi-user scenario, as complex concepts might be easier to illustrate through sketching than describing them with words. A corresponding *whiteboard* metaphor was already mentions in Section 2.2.5.

Sketching is a powerful and fast alternative to many other input techniques. Ideas and concepts can be visualized even without drawing accurately [JS10]. An example of 3D sketched input in the medical field can be found in [SSPOJ16]. It presents a framework to sketch vessels and pathologies, using the semi-immersive *zSpace* (Section 4.1.2) with its stylus as input device. This approach lets a user draw center lines and the surface is modelled accordingly in real-time, applying resampling of noisy tracking data and smoothing the constructed surface.

2.3.5 Usability

In the development of human-computer interaction *usablility* is an important factor. Usability can be defined as follows:

> ”Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.”
> (ISO 9241-11[4])

With the aim of improving human-computer interaction, Molich and Nielsen [MN90] classified usability problems as a guideline for user interface design. It is recommended to already consider them in the design phase. They state that any system should be easy to learn and remember, effective, and pleasant to use. This corresponds to the above definition. The guidelines are as follows:

Simple and Natural Dialogue Leave out irrelevant or rarely needed information, in order to focus on the important parts. All information should appear in a natural and logical order.

Speak the User’s Language Dialogue should use words familiar to the user.

Minimize the User’s Memory Load The user should not have to remember information from one part of the dialogue to another. Complicated instructions should be simplified.

Be Consistent A particular system action should always be achievable by one particular user action.

Provide Feedback The system should always keep the user informed about what is going on with appropriate feedback.

Provide Clearly Marked Exits The system should provide visible escapes for unwanted states.

[4] https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-1:v1:en (accessed: 31.05.2017)

Provide Shortcuts Shortcuts for experienced users enable skipping explanations that are necessary for novice users.

Provide Good Error Messages Good error messages are defensive, precise and constructive.

Error Prevention Ideally no error messages are necessary.

Even though 3D interaction techniques and metaphors are intensively researched, the usability of current 3D UIs in real-world applications is still not satisfactory [BCW+06]. Therefore, further research and the development of new techniques is still worthwhile.

Figure 2.5: A taxonomy of selection and manipulation [BH99]

3. A One-on-One Tutoring Approach for Shared VR

The motivation for this work is based on the fact that self-guided learning is not always effective. Existing computer-based applications that support anatomy education are praised for providing a personal learning experience, where the medical student can navigate freely, focus on aspects of individual interest and advance at his own pace (see Section 2.1.1). Without instructions, however, the student may waste time following unproductive paths or may even miss important details (see Section 2.2.4). This is where the innovative approach of a VR one-on-one tutoring system for a teacher and a student steps in.

To start off, this chapter formulates the objective of the developed concept (Section 3.1). The education scenario is further specified (Section 3.2) and the two primary stakeholders, teacher and student, are discussed (Section 3.3), in order to identify the specific requirements for both sides of the system. Section 3.3.1 points out the requirements for the student system and Section 3.3.2 those of the teacher system.
A semi-immersive VR system for the teacher is introduced (Section 3.6), while describing its functionality in detail. Following, a fully immersive system for the student is discussed (Section 3.5).

3.1 Objective

The main objective of the introduced VR one-on-one tutoring approach is to improve a medical student's learning experience within a Virtual Reality learning environment. The idea is, to enhance the free exploration method by allowing a teacher to guide the student in a shared virtual environment. The teacher shall help the student navigate through the virtual world, in order to find certain structures, as well as giving explanations using annotations. Further, there will be someone for the student to address,

if questions arise.
One-on-one tutoring is a powerful tool of instruction, outplaying other instruction methods in effectiveness (see Section 2.2.6). The concept includes the use of Virtual Reality devices for both the student and the teacher, in order to take advantage of immersion and the natural way of interaction (see Section 2.2).
The following sections work out the specific requirements for the system.

3.2 The Education Scenario

The education scenario that the system shall support can be outlined as follows: As an initial concept, a one-on-one setting is considered, involving only a teacher and one student. The student explores a virtual anatomy model through a fully immersive Virtual Reality device. As the student's real environment is completely blocked out, due to the worn HMD, the teacher needs to join the virtual environment in order to guide the student. Thus, he also uses a VR device to interact in the virtual world. To enable such a shared Virtual Reality, a network connection is necessary to synchronize information. The two roles, teacher and student, are further discussed in Section 3.3.
Both teacher and student will be located in the same room while using the system, since an evaluation of a first prototype is easier to control with both systems in one location. However, a remote usage, as one great potential of shared VR (see Section 2.2.5), will be kept in mind as a future extension. The main communication between the users will be spoken dialogue. The idea is, that the concept will immediately work for remote usage, only by adding synchronized audio in- and output.

3.2.1 The Human Base of the Skull as an Application Example

The focus of this work is on gross anatomy and the human base of the skull shall serve as an application example. Learning the anatomy of the skull is an integral part of anatomy education. Textbooks about human anatomy, e.g., [Cun18], [Ham82], describe the human skull in detail and anatomy atlases (e.g. [PP00]) contain illustrations from different perspectives to help understand spacial relations. The term *skull* (cranium) is used to describe the entire skeleton of the head. The *base* of the skull describes the most inferior area of the skull.

The following identification of requirements for the system to develop is based on an interview between *Manuel Kosta* and a teaching person of the *Institute of Anatomy* of the *Otto-von-Guericke University Magdeburg* for a project that also focussed on learning the anatomy of the human base of the skull.
The human base of the skull has several holes (foramina) through which arteries, veins and cranial nerves (those that directly emerge from the brain) pass (see Figure 3.1). One objective of medical students is to learn these foramina of the human base of the skull by their name and location, together with the structures that pass them. Hereby, the precise course of the structures is secondary. More importantly, students have to understand which organs they further lead to. Regarding the cranial nerves, it is also important to understand, what their specific tasks are (control muscles or glands,

transmit sensory impressions).
Illustrations in anatomy atlases use a consistent color scheme to distinguish arteries, veins and nerves. Therefore, it is useful to also adapt this scheme for computer-based approaches: arteries are depicted red, veins are blue and nerves are yellow.

Figure 3.1: A labelled 2D illustration showing the internal surface of the base of the skull with several foramina labelled, retrieved from [PP00].

3.3 Defining the Roles: Teacher and Student

Having two distinct sides of the system, with users that follow different goals, a separate analysis of their specific requirements is necessary. Understanding the roles that the student and teacher occupy, helps to decide, which devices and input techniques are suitable. This approach corresponds with an asymmetric setting, similar to [LCDL+16], which is further described in Section 2.2.5.

3.3.1 Requirements for the Student System

The target group for the student system is an undergraduate student who is enrolled in a medical curriculum. Here, anatomy education is an integral part, especially in the first years of study [SAK10]. The student's main goal is to learn about the anatomy of the human base of the skull. Following the thoughts of Section 3.2.1, a medical student especially wants to acquire knowledge about foramina and their passing structures. Arising form this objective, several requirements for the student system can be worked out:

Immersion Especially fully immersive VR interfaces are considered to provide a great benefit for learning (see Section 2.2.4). Such innovative devices enhance motivation and the feeling of immersion augments learning with experience. Thus, a fully immersive VR device is the best choice for the student system.

Information is Directly Linked to Structures To enhance learning, the student needs to develop a cognitive model of the anatomy structures. This is facilitated, when the spacial- and symbolic domain of information (see Section 2.1) are linked appropriately. Therefore, symbolic output needs to be provided, in order to augment the virtual models with their names and descriptions.

Recognize Small Details In an evaluation of interaction techniques for the exploration of 3D illustrations [PPS99] it was observed that medical students tend to enlarge the virtual model strongly to recognize small details. Since the VR environment is not bound to space limitations like the real world, a drastic enlargement of the anatomic structures is possible.

Natural and Intuitive Navigation, without Disorientation To gather the full spacial domain, the student needs to be able to navigate through the virtual environment. Position tracking and motion controllers allow a natural and intuitive interface for navigation in a fully immersive environment. Sophisticated navigation techniques need to be implemented, that allow the student to travel and reach distant locations with minimal cognitive effort and without disorientation.

Inspection of Single Structures Further, single structures may be partly occluded by other structures. If the student still wants to be able to to inspect a structure closely, dedicated selection and manipulation techniques need to be implemented. Structures in sight need to be globally selectable, to avoid unnecessary navigation.

Intuitive and Easy to Learn Interface When the student enters the one-on-one tutoring setting, he should not take a lot of time trying to learn about the controls, as this would waste precious time of the present teacher. Thus, the interface should provide initial help to let the student easily understand the controls, so he can further concentrate on the education scenario.

The student is the receiver in this education scenario. His main objective is to inspect the anatomical structures. Arising questions will be communicated through spoken dialogue. Thus, the student does not create any objects that need to be synchronized with the teacher system. The only value to synchronize is the students position and orientation.

3.3.2 Requirements for the Teacher System

The target group for the teacher system consist of teaching staff of medical educational facilities. The main goal for the educator using this system is to support a medical student in the acquisition of knowledge about the anatomical structures of the human base of the skull. Based on the student system discussed above, the teacher system needs to provide an interface to intervene in the virtual environment that is explored by the student. This leads to the following requirements for the teacher system:

Balance of Immersion and Access to the Real World As the teacher is already familiar with the anatomy of the human base of the skull, the benefits of full immersion are less relevant. However, the teacher might need to have access to prepared notes or a keyboard for text input. Considering this, a fully immersive VR system that completely blocks out the virtual world is not appropriate for the teacher's needs. This makes a semi-immersive system the best fit.

Awareness of Student's Position and Orientation In order to perform guidance, the teacher has to be aware of the student's location within the virtual environment at any time. Thus, the student needs to be represented by an avatar at the according location on the teacher's system. Also the viewing direction needs to be displayed with respective rotation of the avatar.

Improve the Student's Navigation The teacher shall help the student navigate through the virtual environment. In order to lead him to a specific location, an input to give the student a hint needs to be realized. Further, facing the problem that self-guided exploration can take an unnecessarily long time, the teacher needs to be able to completely alter the position of the student and place him at a desired location.

Provide Annotations for the Student The creation of content for the symbolic domain has do be provided at runtime. Textual input is best suited for annotations of names and descriptions. Using labels, the spacial and symbolic domain can be linked effectively. If the teacher wants to highlight a certain area or illustrate concepts, textual input is not suitable. Following a virtual whiteboard metaphor, 3D sketched annotations are a powerful tool to perform such a task.

Edit and Delete Annotations When creating annotations, errors may occur. Unwanted input needs to be editable and deletable. The creation, editing and deletion of each annotation needs to be synchronized over the network for them to be displayed accordingly on the student's system.

Display and Hide Annotations on the Student System The teacher might prepare several annotations in advance and wants to have control over the moment when they are displayed on the student's system. This can be seen as an equivalent to prepared slides for a lecture. Thus, the teacher shall be able to display or hide a specific annotation at any time on the student's system.

Effective Change of the View To perform the above mentioned tasks, an intuitive way of navigation needs to be implemented for the semi-immersive system. The system needs to provide an effective way to let the teacher focus on a desired location.

3.4 The Shared Virtual Environment

Deriving from the requirement that the student needs to recognize small anatomy details, a drastically oversized skull model is places in the virtual environment. The student being represented much smaller, can navigate within the model while obtaining a micro view of the base of the skull. He is immersed in an environment where the bones of the skull form the walls around him. Thus, small details can be explored without the need of further scaling.
The teacher, on the other hand, has a takes an overview position within the environment. He looks down at the student, in order to follow his position and orientation. Details are not as important to the teacher, who is already familiar with the anatomy. He is more interested in maintaining an overview of the scenario. Figure 3.2 illustrates this asymmetric setting and shows the initial position of both users in within the skull together with their viewport.

The student is presented through an avatar on the teacher system. The avatar is positioned according to synchronized data. This way, the teacher can track the students behaviour. The representation of the avatar is kept simple, indicating the orientation with a simplified illustration of VR head-wear (see Figure 3.3). This way, no unnecessary detail can distract the users. It further has a *Toon Shading* [LC00], in order to contrast with the environment.
Even though previous researches about shared virtual environments use a representation of all users through an avatar, the teacher will not be presented with an avatar on the student system. As the base of the skull represents a hollow earth environment, a big avatar looking down at the student will likely block out interesting structures.

3.5 The Immersive Student System

The advantages of immersion through Virtual Reality have been discussed in Section 2.2.4. To make use of this benefits, one requirement for the student system is, to design it for a fully immersive system. As described in Section 2.2.3 there are several current devices available. HMDs are a favourable choice, as they are easier to integrate within a learning environment. They are becoming more affordable and the setup is less

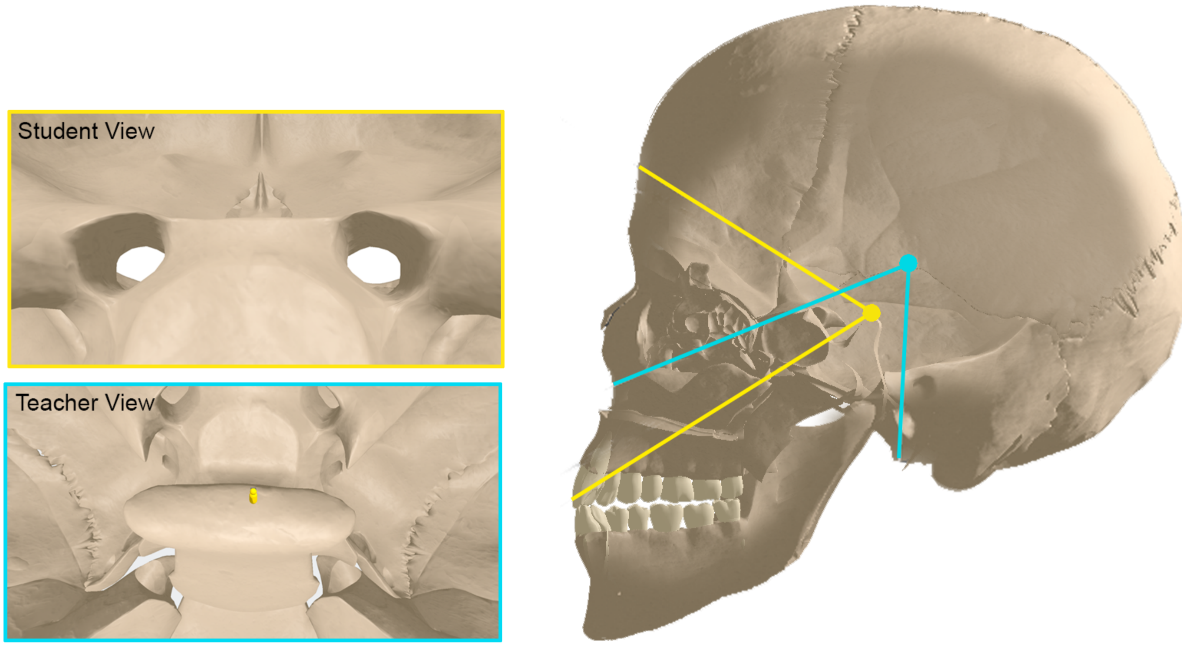

Figure 3.2: Illustration of the initial viewports of student and teacher within the virtual environment.

problematic than the setup of systems like a *CAVE*. Even though, mobile devices are cheaper and easier to use with several students at a time, sophisticated input devices for mobile HMS are missing and their hardware does not allow demanding 3D applications. Thus, one of the leading HMDs on the market is the best choice. The *HTC Vive* stands out through its room-scale position tracking and, thus, allows navigation through natural walking within the tracked area. Together with the two 6-DOF motion controllers, this makes the *HTC Vive* a perfect device for the fully immersive experience of the student. See Section 4.1.1 for a detailed look on the specifications of the device.

The following sections present the user interface of the student system and discuss its functionality in detail.

Figure 3.3: The student's avatar on the teacher system.

3.5.1 User Interface

The student has one motion controller in each hand. Figure 3.4)[1] illustrates the controllers with their assignment of the buttons. The left controller is the *Menu Controller*. It displays a menu, while the right controller as *Interaction Controller* enables selection through ray-casting and is used for navigation. Both controllers can be swapped to suit left-handed an right-handed users equally.

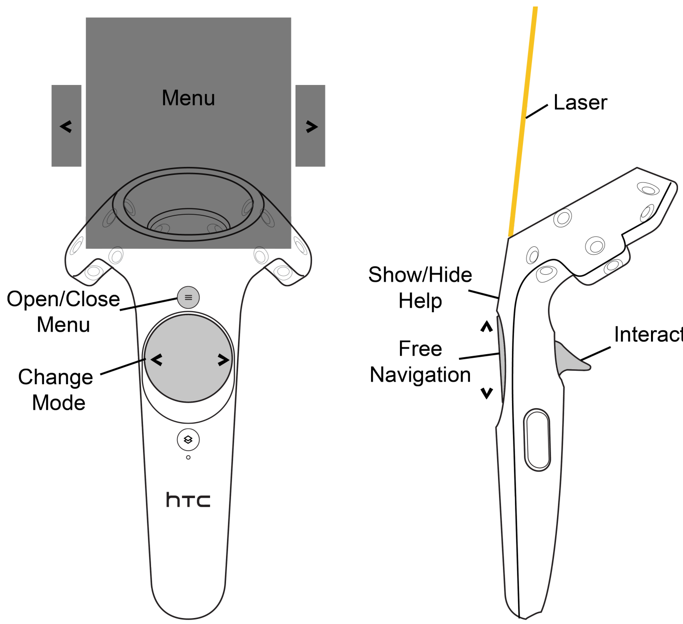

Figure 3.4: The illustration shows the assignment of buttons for the *HTC Vive* controllers. Left: the *Menu Controller*. Right: the *Interaction Controller*.

The Menu Controller

A menu is attached on top of the controller. According to Section 2.3.3, this approach is an *object fixed* UI. It is part of the 3D scene and moves with a specific object. This placement shall create a *handbook metaphor*, since an attachment to the controller lets the user have the menu always at hand. This way, readability of textual content is less of a problem. If the menu text appears too small, the user is able to hold the menu nearer to his eyes. Information about the virtual objects within the environment are displayed here and the user can browse through different menu pages to change the interaction mode. Figure 3.5 shows the three menu pages. The corresponding modes and the according functionalities are outlines in the following sections.

The backround of the menu is semi-transparent. This way it will not occlude the virtual world completely. If a user still feels distracted by the menu, the small menu button of the controller enables him to open and close it. Browsing through the pages is done

[1]Based on an illustration of the *HTC Vive* devices, taken from: https://www.vive.com/de/support/category_howto/about-the-controllers.html (accessed: 31.05.2017)

with the left and right button of the touchpad. Further, two buttons on the side of the menu indicate, that there are pages to switch through. These can also be used for doing so. In order to interact with virtual buttons like these, the interaction controller is used.

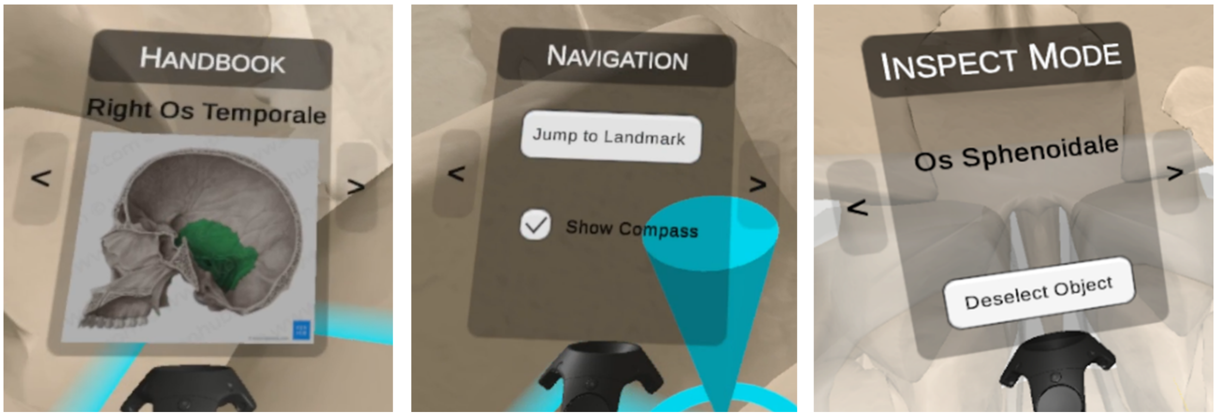

Figure 3.5: The three menu pages of the *HTC Vive* system. Each of them represents an interaction mode. Left: Handbook. Center: Navigation. Right: Inspect.

The Interaction Controller

The *Interaction Controller* should be used with the prominent hand as it is used for pointing and selection tasks, while the *Menu Controller* is merely a place of reference to be hold in the other hand. A laser beam originates from to top of the controller and follows its pointing direction. It is uses for a ray-cast method of interaction. This way, distant objects can be pointed at and selected without the need of navigation towards them. A selection task performed with the stylus can be decomposed following the taxonomy of Bowman et al. [BH99] (see Figure 2.5). To indicate an object for selection, the user points at it with the *Interaction Controller*. With the 6-DOF an intuitive and natural handling is possible. The first selectable virtual object that the ray hits is highlighted. This graphical feedback is accompanied by a tactile feedback, as the controller offers vibration. This simulates the sense of having hit something. The trigger on the back of the controller is used to indicate the selection. If a selectable object is in range of the user, like buttons on the menu, he can also select it by directly touching the object with the controller. As this is similar to interaction in the real world, this increases the feeling of immersion.

The color of the laser is orange-yellow, to contrast the environment and follow a light beam metaphor. It is always visible and cannot be hidden like the menu on the other controller. The laser serves as a point of orientation and it allows a clear distinction of the two controllers at any time. Moreover, the *Interaction Controller* is used for navigation tasks. The touchpad can be used for freely flying through the environment. This is further discussed in Section 3.5.3.

When starting the system, each functionality of the buttons on both controllers is displayed with a label, in order to help the student getting familiar with the controls. These labels can be hidden and displayed again through pressing the menu button on the *Interaction Controller* (see Figure 3.6).

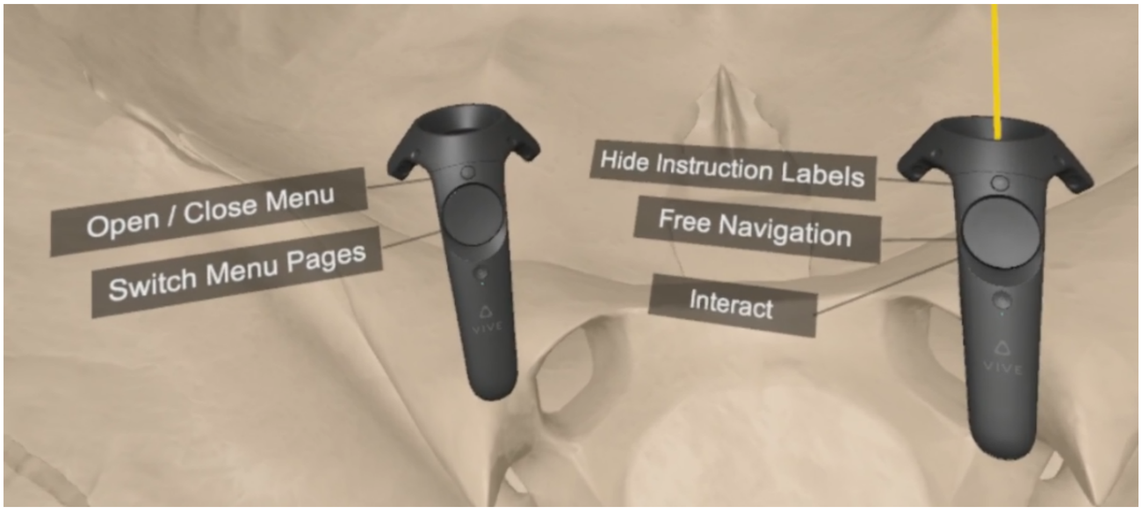

Figure 3.6: Labels on both controllers introduce he student to the basic controls.

3.5.2 The Handbook Functionality

The first mode of the student system is the *handbook* functionality. It is the default mode when the system is started and is perfect for exploring the virtual world. Whenever the ray hits an object that includes further information, this information is displayed on the menu.
In the case of the application scenario, every bone of the skull comprises information about its name, a short description or a 2D illustration, in order to link the 3D information acquired in VR to the common illustrations in anatomy atlases (see Figure 3.5, left). Further, information of a hovered label is displayed in the handbook. This way, the user does not have to navigate near to the label. If a label is too far away for reading its text, the handbook can be used.

3.5.3 Navigation Methods

The student system offers different ways of navigation, *Walking*, *Free Flying* and *Teleport*. Following, their detailed functionality is discussed.

Walking

As the *HTC Vive* offers a room-scale experience with position tracking, walking in the real world can be mapped to the virtual environment. The available space for walking is indicated through a barrier in the virtual world. This way, a collision with walls or objects is prevented. This intuitive and natural navigation can be used for manoeuvring around a limited area to get different viewing angels on a location of interest.

Free Flying

As the virtual environment is larger then the available space for walking in the real world, another way of navigation needs to be offered to the student, in order to reach every desired location within the virtual world. Corresponding to a flying carpet metaphor the student can fly freely in every direction. The barrier that indicates the space for walking serves as orientation and gives the feeling of standing on a virtual platform or carpet. Even though an opaque platform could be more helpful for the sense of standing on firm ground, this would block the view of the student.

The *Free Flying* is controlled with the touchpad of the *Interaction Controller*. Decomposing the travel tasks according to Bowman et al. (see Figure 2.4), the movement is started when pressing the touchpad (up, down, left or right). The new position in continuously specified through a pointing technique: the moving direction is indicated through the orientation of the *Interaction Controller*. When releasing the press on the touchpad, the student stops moving.
The direction of movement in HMD setups with motion controllers can be determined in different ways (see Figure 3.7)[2]. A common method is, to move in the viewing direction, determined by the orientation of the headset. This is very intuitive, as people usually look forward when walking, in order to avoid collisions. This method, however, has a strong disadvantage. As the student is meant to explore the virtual environment, this involves looking around. When the movement is influenced by the viewing direction, it is hardly possible to navigate and look around at the same time. Further, especially an upward movement would need the user to turn the head upwards, which can be uncomfortable after a while. Using the orientation of the controller to determine the moving direction is an alternative. IIn [Min95] it is stated that it can be confusing for novice users who often don't fully understand the relationship between hand orientation and flying direction. However, this approach allows full freedom of navigation while looking around. Thus, this approach is used for the student system. Other movements instead of a forward direction, using the down, left or right button of the touchpad, is, thus, also oriented towards the controller orientation.

The *Free Flying* can be used at any time and is not dependent on the active mode. The speed of movement is predetermined and not modifiable, as this would complicate the intuitive navigation method. If larger distances need to be overcome, the *Teleport* is an alternative.

Teleport

There is a *Navigation Mode* for the student system, which is presented as one page of the menu (see Figure 3.5, center). When activated, this mode offers a *teleport* method for fast navigation and allows the student to directly jump to a landmark that was placed by the teacher (see Section 3.6.3).

[2] Based on an illustration of the *HTC Vive* devices, taken from: https://www.vive.com/de/support/category_howto/about-the-controllers.html (accessed: 31.05.2017)

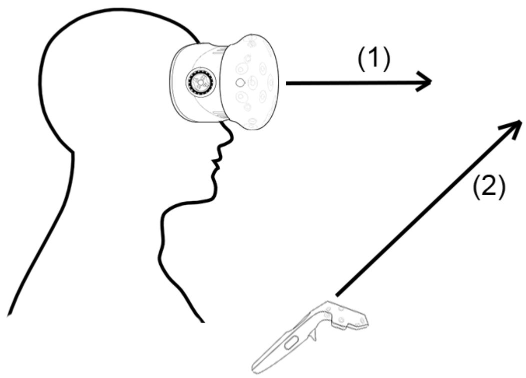

Figure 3.7: Illustration on possibilities to determine the moving direction: (1) move according to the headset orientation, (2) move according to the controller orientation.

When the *Navigation Mode* is active, the yellow-orange laser is replaced with a teleport laser. To make this laser distinguishable from the standard laser, it has a different colour. A blue color is chosen, equal to the barrier for walking, in order to communicate that both UI elements belong to a similar field of tasks.
While the length of the standard laser is determined by the first object it hits, the length of the teleport laser is set to a specific value that is adjustable. A capsule at the tip of the laser highlights the target location for teleporting (see Figure 3.8). The student can use the touchpad of the *Interaction Controller* to swipe up and down. This regulates the teleporting distance and the laser changes its length accordingly.
The *Teleport* is a goal-directed technique. Analysing the subtasks, the indication of position and orientation are determined before starting to move. The target position is specified through the laser tip position, which is dependent on the adjusted length and the controller orientation. To initialize movement, the student presses the trigger button of the *Interaction Controller*. The position is instantly altered to the new target position.

Even though this is a fast method to overcome longer distances, the student may lose orientation. An alternative could be a transition to the new position, instead of a direct jump. However, such automatic movements can evoke *cybersickness* easily (see Section 2.3.1). If the student suffers from cybersickness due to the VR system, he will not be able to continue using it. Losing the orientation through a direct jump is also not desirable, but will not prevent the student form continuing to use the system. Thus, the direct jump approach without transition is used for the student system.

The student shall only be able to teleport to locations in sight, in order to reduce the danger of lost orientation. Thus, teleporting through walls should not be possible. Especially teleporting to a location within a wall is unwanted. Figure 3.8 illustrates an approach how this will be avoided. Situation (1) of the illustration shows the standard situation with sufficiant space between the target location and the wall. In situation (2), the student would usually teleport through the wall. In this case, the laser is shortened automatically, until a bounding box around the laser tip, that assures a minimum distance, does not collide with the wall any longer. This way, the student will always have a comfortable distance to walls when teleporting and is not able to teleport into to small corridors. If the student still wants to pass a wall or travel a small corridor that makes him being stuck within a wall, he can use the *Free Flying*.

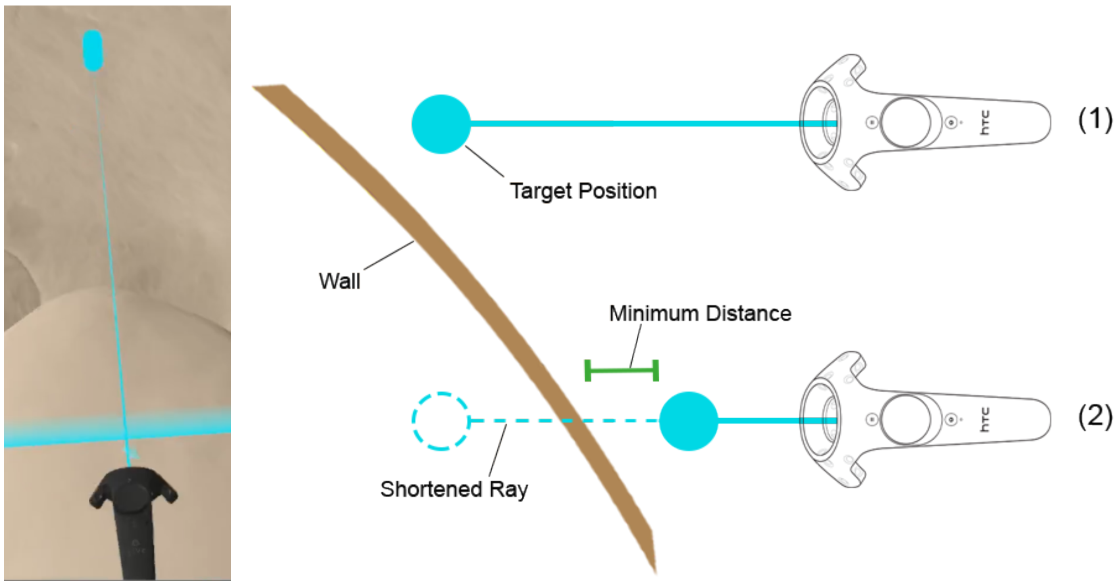

Figure 3.8: Left: The adjustable ray for teleporting shows the target location through a capsule at the tip. Right: In order to avoid teleporting through a wall, the teleport-ray is shortened until there is a minimum distance between the wall and the target location.

3.5.4 Inspecting Objects

Due to the large scale of the skull bones, the student may have difficulties to get a full image of a single bone. Some parts of a single bone may be occluded or hard to reach through navigation. In the *Inspect Mode*, as a third page of the controller menu, the student can select one of the skull bones for further inspection. A smaller copy of the single bone is places within the students reach, while the original structure is displayed semi-transparent (see Figure 3.9). On the one hand, this highlights the location of the inspected object within the environment and, on the other had, usually occluded structures may become visible through the transparency. The student can use both controllers to grab and manipulate the position and rotation of the copy. This direct manipulation through contact is used in order to make the manipulation process resemble natural interaction. The student presses and holds the trigger button of a controller that collides with the bone copy. The object will be attached to the respective controller and will move accordingly. As soon as the student releases the trigger button, the bone copy will stay in the new location. The bone copy will move with the student when navigating and will, thus, always stay in reach. Even when the student leaves the inspection mode, the copy will stay present and can be manipulated. If the student wants to delete the copy or select another, he needs to switch back to the inspection mode menu page. This parallel usage of inspecting a small copy while exploring the environment can help the student to achieve a better understanding of the 3D structures.

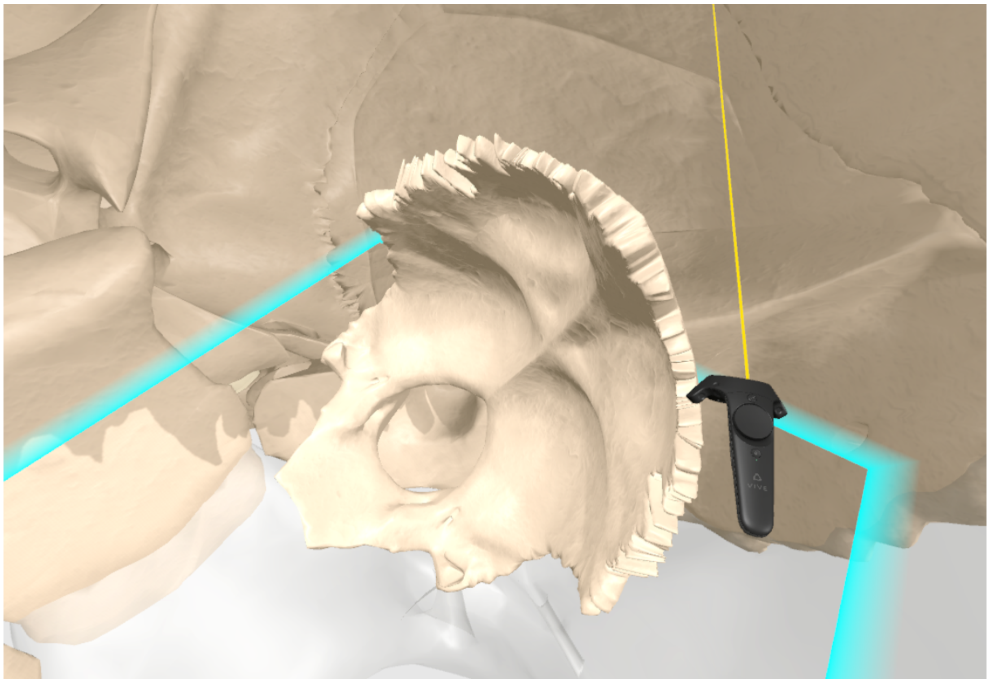

Figure 3.9: A small copy of a selected skull bone can be inspected closely. The original structure is shown semi-transparent in the background.

3.6 The Semi-immersive Teacher System

According to the requirements for the teacher system, a balance between immersion and access to the real world shall be provided. In order to be able to interact effectively within the virtual environment, a 3D input and output device is important for the teacher. A fully immersive system like an HMD, which blocks out the real environment, however, is not useful, as the teacher needs to use a keyboard and may want to have access to prepared notes. A semi-immersive system is a perfect compromise to benefit from immersive interaction and still being able to sense the real workspace.

The *zSpace* is a semi-immersive device that combines a stereoscopic display with head-tracking (so-called *Fish Tank VR*, see also Section 2.2.3). Further, it provides a stylus as a 6-DOF pen-based input device, which is ideal for a natural input and especially suited for the required 3D sketch input. Researches like [SBL+15] already used the *zSpace* in the context of exploring anatomy structures effectively. The *zSpace* suits the requirements for the teacher system and is, thus, used for the prototype implementation. A detailed introduction on the device is found in Section 4.1.2.

The following sections present the user interface of the teacher system and discuss its functionality in detail.

3.6.1 User Interface

The GUI

Following an analysis of 3D user interfaces for stereoscopic devices in [SBLJM13] (as described in Section 2.3.3), a *view fixed* system control interface is chosen. It is always rendered on top of the scene. This way, it will not be occluded by the 3D environment, which could otherwise have a significant impact on the usability, as the teacher would have to adjust the view in order to reach a specific button. It was further determined, that users preferred a menu attached to the bottom display frame.

Figure 3.10 shows the the menu bar attached to the bottom display frame of the *zSpace*. It has a semi-transparent background, as proposed in [SBLJM13], in order to allow the 3D environment show through and not being completely occluded. If the teacher wishes to have a full view on the 3D environment, it is possible to hide the menu bar with a small button on the left.
To access specific functionality, windows are displayed. These windows are similar to the *WIMP* metaphor (see Section 2.3.3), as they can be dragged to a desired position on the screen, while holding the top window bar. Further, a close icon is placed in the top right corner. As these concepts are commonly known, it is intuitive to use.
The interface is designed to fit right-handed and left-handed users equally. The menu bar is easily accessible with both hands, as it is centred and the windows can be positioned individually at any position.

Buttons of the menu bar use icons to indicate the functionality, instead of a textual description. They shall promote an intuitive understanding of the functionality. Specifically for object creation tasks, the icon directly represents the according object.

Figure 3.10: The *view fixed* user interface of the semi-immersive teacher system: (a) access to the *interaction modes*, (b) open/close windows for *global functionality*, (c) windows can be dragged to a desired screen position

The Stylus and Ray-Casting

The stylus of the *zSpace* can be used for pointing tasks, as the elongated form indicates the pointing direction intuitively. Using the ray-casting method, a virtual ray originating from the tip of the stylus, following along the pointing direction, extends the operating range.

The method is equivalent to the ray-casting used with the semi-immersive student system, as described in Section 3.5.1. To indicate an object for selection, the user points at it using the stylus. With 6-DOF an intuitive and natural handling is possible. The first selectable virtual object that the ray hits is highlighted. This graphical feedback is accompanied by a tactile feedback, as the stylus offers vibration. When starting to hover a selectable object, the stylus slightly vibrates. The selection of the hovered object is indicated by pressing a button on the stylus. The device offers three buttons. The layout is shown in Figure 3.11. The upper main button is used for interaction tasks that vary depending on the active interaction mode of the system. The other two button enable the user to adjust the view at any time (see also Section 3.6.7).

The ray is being visualised as a yellow-orange laser beam originating from the tip of the stylus (corresponding to the laser in the student system, see Section 3.5.1). Usually the length of the laser is determined by the object that is hit. In some cases, depending on the mode of interaction, the laser may have a predefined length, e.g., in the *3D Sketch* mode (see Section 3.6.5).

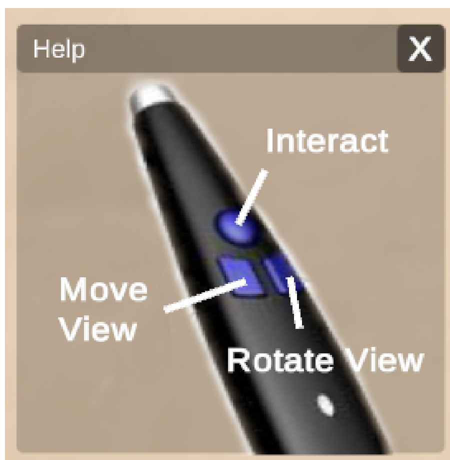

Figure 3.11: An illustration of the button layout of the *zSpace* stylus, illustrated in a help window.

3.6.2 Functionality Overview

The above presented menu bar (see Figure 3.10) comprises two different categories of buttons. An overview on their functionality is briefly given, while a detailed discussion follows in the upcoming sections.

Interaction Modes On the left side, three buttons allow switching between *interaction modes*. Only one of the modes can be active at a time, as they provide specific functionality. It is also possible to have all three modes inactive. This *neutral* mode only offers the *global functionality*, but is useful for a general observing task, as no unnecessary tools and interfaces block the view. Following, a short outline on the four modes:

- **Neutral** This mode is active if none of the below three is selected. The teacher can navigate the environment and observe what the student is doing.
- **Landmark** In this mode the teacher can place a landmark in the environment, which is then spawned on the student system, to guide the student's navigation (see Section 3.6.3).
- **Label** The teacher can position a label and edit its text, which is then spawned on the student system (see Section 3.6.4).
- **3D Sketch** 3D Sketches allow annotations that are synchronized with the student system (see Section 3.6.5).

Global Functionality The buttons on the right side of the menu bar offer *global functionality* that can be accessed while each of the *interaction modes* is active. The toggle buttons display and hide corresponding windows that provide control elements for the inquired functionality. If the teacher wants to have access to the specific funtionality, he opens the according window. Otherwise, he can close them, in order to have fewer UI elements that occlude the 3D environment. These functionalities comrise the following:

- **Adjust View** The teacher can translate and rotate the view to focus on a desired location (see Section 3.6.7).
- **Reposition Student** The teacher can grab the student's avatar and drag him to a desired position (see Section 3.6.3).
- **Display Student View** Even though there is an avatar of the student, it can be helpful to see what he actually sees. The teacher can decide on if he wants to display this view (see Section 3.6.7).
- **Focus on Student** If the teacher loses track of the students location, he needs to be able to refocus on him (see Section 3.6.7).
- **Hide Annotations** Annotations are automatically clustered into groups. The teacher can decide about the visibility of each group on the student system (see Section 3.6.6).
- **Help** An illustration of the button layout of the stylus can be opened in a window (see Figure 3.11).

3.6.3 Guiding the Student's Navigation

Following the motivation for this work, the main objective for guiding the student lies in supporting his navigation, in order to help him follow a more productive path. The teacher system offers two different approaches. The teacher may indirectly lead the student to a desired location, through placing a landmark at the target position. The student still has to navigate on his own, but wayfinding will be improved as he now has an object of orientation. Further, the teacher may want to take full control over the student's position. He can actively position the student at a desired location.

Setting a Landmark

The landmark shall be an object that is easily noticeable in form and colour within the virtual environment. Therefore, a geometric primitive is chosen. As a simple cone it marks a desired target location. Coloured in cyan, it will stand out within the environment that mainly contains the skull bone objects. A clear distinction is further given through a *Toon Shading* of the landmark object (see Figure 3.12). A slight animation of the cone jumping up and down draws the attention towards the landmark.

To place a landmark into the environment, the teacher needs to activate the *Landmark Interaction Mode*. There can only be one landmark at a time. If he places a new landmark, the old one will be replaced. The landmark is meant to guide the student to a location of interest. Thus, several landmarks are not useful and would be confusing. If the teacher wants to mark several locations, the landmark is not the right tool. Instead, he may use one of the annotation modes (Label or 3D Sketch). The teacher may then guide the student to one annotation at a time using the landmark.
The landmark should only be placed onto or next to a surface, as the anatomy details of interest are formed my the bones of the skull. Thus, target locations are usually bound to the surface of the virtual skull object. Further, guiding to a surface location will help the student's orientation, as a vast location in the 3D space does not have reference points. To achieve a placement near the surface, the ray-cast method is uses, where the length of the ray is determined by the hit-point with the surface. The length of the ray is always adjusted accordingly. To avoid, that the landmark is stuck within the surface, the same approach as for the *teleport* functionality of the student system is used (see Section 3.5.3). A semi-transparent copy of the landmark object is placed at the tip of the ray, to visualise where the landmark will be positioned exactly, after indicating to place it with the interaction button of the stylus (see Figure 3.12).
If the teacher does not want to have a landmark present any more, after having placed one in the environment, he can delete it via a button in a window that opens up when the *Landmark Interaction Mode* is activated.

The landmark is synchronized over the network and appears on the student system. When a landmark is placed or updated to a new position, the student is informed through a vibration feedback of the controller he uses for navigation. Further, if a landmark is active, an arrow is placed at the controller, always facing into the direction of the landmark (see Figure 3.12). Analogous to following the direction of a compass needle, the student can easily navigate towards the marked location. Further, if the student switches into the navigation mode, he has the possibility to directly jump to the landmark. A corresponding button is found on the navigation page of the menu on the *HTC Vive* controller (see Figure 3.5, center).

Reposition Student

Even though the landmark can lead the student to a desired location, it can still be helpful to actively change the student's position. If the teacher wants to start the lesson at a specific location, he can directly place the student as desired. Thus the student

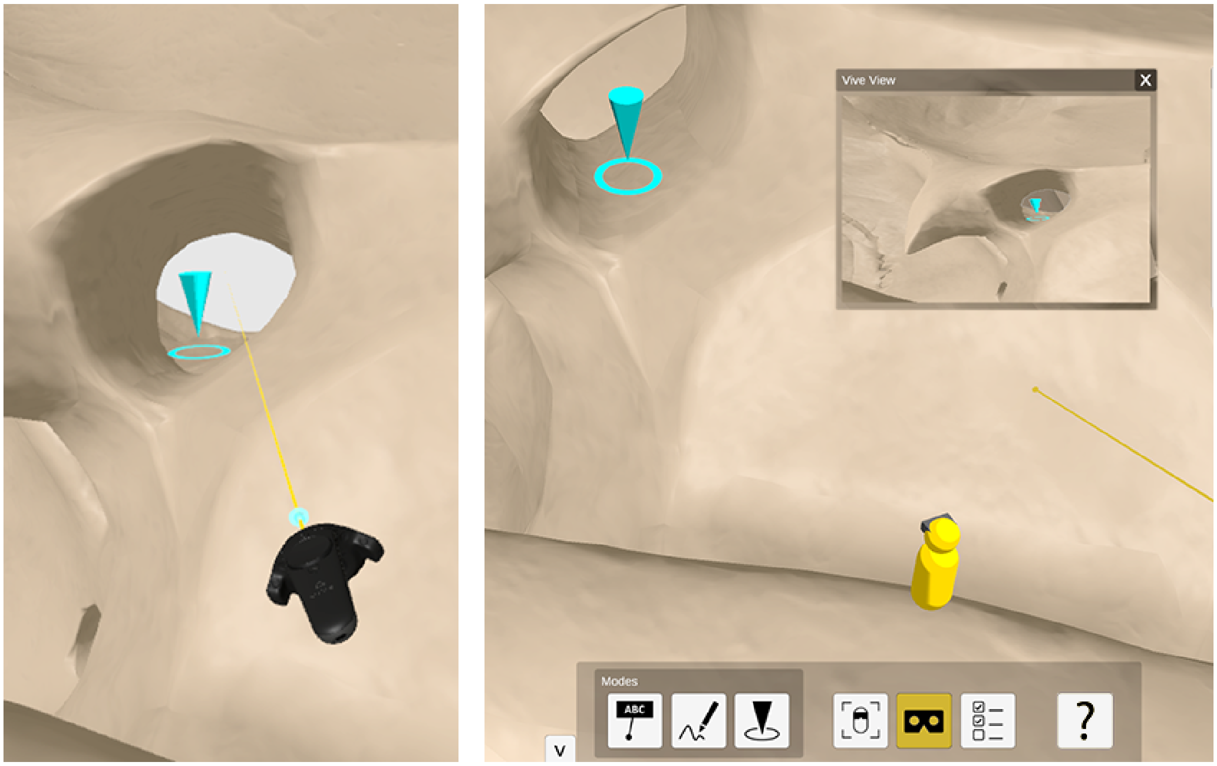

Figure 3.12: Left: The student's view on a landmark. Right: The corresponding view on the teacher system. The student's avatar can be seen, looking right at the landmark. The student's view is further shown in the window at the top right.

does not have to start with navigating to the right place, but is directly positioned correctly. Further, a navigation task might take too long, even with the help of the landmark. If the student has problems navigating and orienting himself, the teacher can completely take over this part and the student can concentrate on exploring the environment in range.

To perform the task of repositioning the student, the teacher manipulates the position of the avatar representing the student on the teacher system. He can select the avatar through hovering it with the laser. When pressing the interaction button on the stylus, he starts manipulating the position through dragging the avatar to a desired location. Releasing the button places the avatar to the new position and the coordinates are synchronized with the student system. The student then directly jumps to the new location. Corresponding to the *teleport*, no transition is being used, in order to avoid *cybersickness* (see Section 3.5.3). To reduce the chance of the student losing orientation, it is recommended to announce the repositioning through spoken dialogue in advance.

It is possible to reposition the student while each one of the modes being active. However, the *neutral* mode is recommended to do so, as no other interaction can distract a correct positioning. Specifically the *3D Sketch* mode has a laser with a specified length, instead of being extended to an object to hit. This can make it complicated to place the student as desired.

3.6.4 Creating Labels

The teacher shall be able to create labels in the virtual scene as annotations and editing them live, while tutoring. Therefore, one of the *Interaction Modes* is the creation of labels. They can only be positioned on a surface, in order to assure a direct link between object and information. The creation of a label is done in three steps (see Figure 3.13). At first, the tip is positioned onto a surface. The laser that is used for positioning, always adjusts its length according to the hit surface. The interaction button on the stylus is clicked to confirm the tip position. Now the user can drag the billboard of the label to a desired location in the 3D space. To make this second positioning task possible, the laser keeps a fixed length. Through individually positioning the billboard, it can be assured that it is not occluded. The billboard location is being confirmed through another click on the interaction button of the stylus. The finished label placement results in a dialogue being displayed, for editing the label details.
It is possible to adjust the tip and billboard position later. While a label is active for editing, its tip or billboard can be picked with the laser and dragged to a new position while pressing the interaction button of the stylus. The orientation of a billboard does not need to be edited, as it will always face the main camera, and thus, the student on the student system and the teachers on the teacher system.

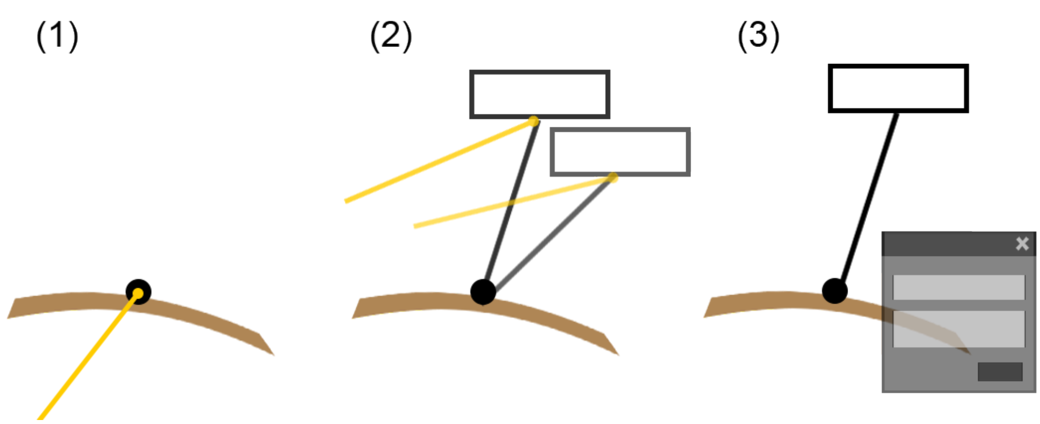

Figure 3.13: A three step concept to creating a label: (1) position tip, (2) drag billboard to desired location, (3) edit label content within window.

The editing window allows the user to type in a headline and a description text that is displayed in smaller letters on the label. Further, each label can be tagged. According to the application example of the base of the skull, it is an objective to learn about the arteries, veins and muscles passing foramina (see Section 3.2.1). Adapting the commonly used colors red, blue and yellow for illustrating them respectively, three different tags can be given to a label (see Figure 3.14). Moreover, the teacher can decide, if the label shall already be visible on the student system. When deciding for invisible, the label is still seen on the teacher system, for further editing, but less opaque. As soon as the teacher clicks the apply button, the edited information is synchronized to the student system. A direct synchronization without confirming the changes (like in the 3D sketch functionality) is not useful with text input. Further, a label can be deleted.

Figure 3.14: A label that is places in the environment can be edited via the label window.

3.6.5 Creating 3D Sketched Annotations

A dedicated input technique shall be provided for the teacher, to allow him sketch structures like vessels and nerves freely in the 3D space, create individual illustrations for explanation and highlight certain areas.

The *3D Sketch Interaction Mode* opens a window with settings for sketching. The teacher can choose from a colour palette of black, white, green, red, blue and yellow (see Figure 3.15). Specifically the last three colours are provided as they are the commonly used ones for illustrating arteries, veins and nerves. This way, the teacher can indicate these structures through sketching. Further, two different line strength are provided. Equal to the labels, the teacher can decide on whether the sketch is currently visible on the student system. If no sketch is active, the settings are made for the sketch that is being drawn next. If an existing sketch is selected with the laser, the changes apply to this sketch and are directly synchronized. A once created sketch can only be changed according to these settings. The actual form is permanent and the sketch can only be deleted as a whole.

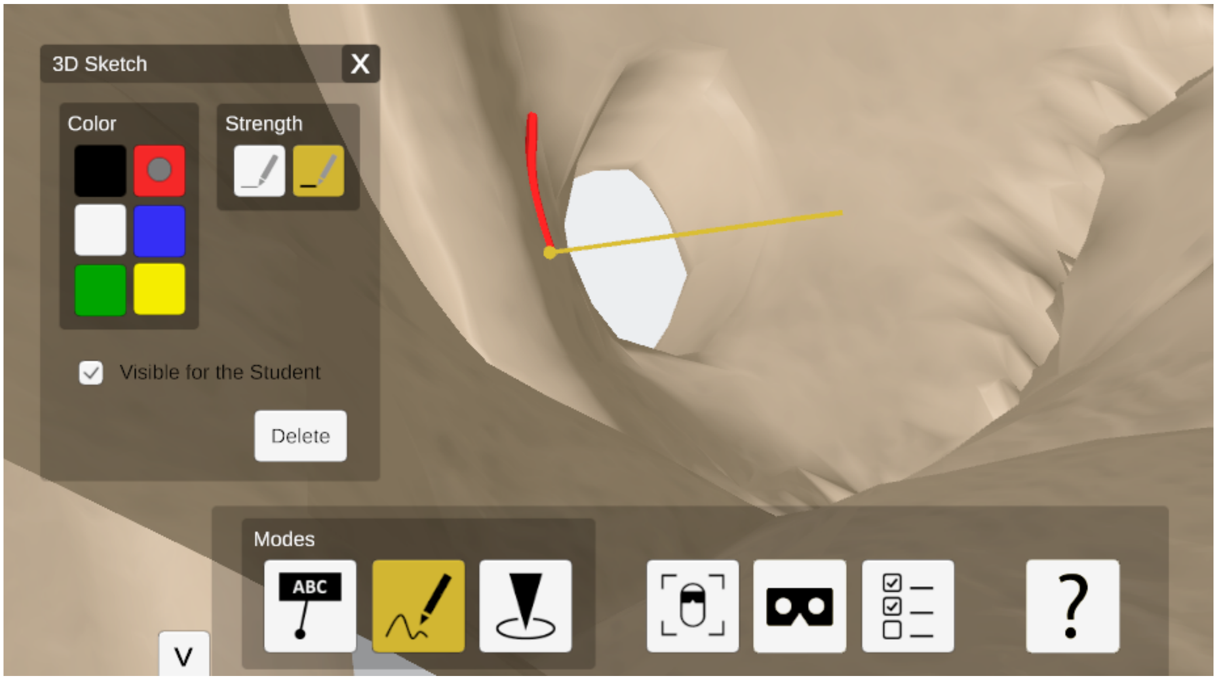

Figure 3.15: The *3D Sketch Mode* is active. The window comprising sketch settings is opened while a red stroke is sketched directly onto the surface.

For creating a sketch, the laser has a predefined length and at its tip the sketch is created. Pressing and holding the interaction button of the stylus initializes sketching. While the button is pressed, the teacher can move the stylus in 3D space to create the sketch. After releasing the button, the shape of the sketch is permanent.
The sketches are synchronized with the student system while being drawn. This way, the student can directly experience the sketching process. The synchronization of a sketch is explained in more detail in Section 4.2.2.

In order to obtain a 3D object from the coordinates of the laser tip, an approach of drawing center lines is used. The position of the laser tip is being sampled in a designated interval. These sampled vertices form lines which could be already rendered as the sketch. However, to appreciate the 3D characteristic of the sketch, a more sophisticated rendering method is used. To each vertex on the acquired line, a ring with a specified radius is being created such that a tube is formed around the center line. The radius specifies the line strength. A *Toon Shading* is applied on the sketches, in order to make them contrast with the environment.

The predefined length of the laser allows the teacher to cross walls while drawing. However, it is more likely that he wants to mark something on a surface. Having parts of the drawing vanish within the geometry is an unwanted outcome. Thus, the laser is shortened, if it crosses the wall, until the tip is directly on the surface. This method is similar to the wall avoidance of the *teleport* navigation of the student system (see Figure 3.8). This concept allows the teacher to draw comfortably onto the surfaces but also within the 3D space.

3.6.6 Hiding Annotations

In order to structure a tutoring lesson, the teacher may not want to display all created annotations at the same time. Deleting those not needed is impractical, as they might be needed again later. Therefore, the teacher has the possibility to hide annotations for the student and display them again when needed. Hidden annotations are only hidden on the student system. The teacher system still displays them, as the teacher need to be able to select them again. To indicate that an annotation is not displayed for the student, it is shown semi-transparent for the teacher (see Figure 3.16).

Figure 3.16: Left: A sketched annotation on the teacher system. Right: A hidden annotiation is displayed semi-transparent.

The *visiblitiy* window can be opened through the menu bar. It presents several check-boxes to decide what groups of annotations are visible to the student. 3D sketches are grouped according to their colour and the labels according to their tags. This way, the teacher can for example choose to only display annotations that are relevant for arteries, through hiding everything other than red sketches and labels that are tagged red.
The teacher can decide for every single annotation if it is displayed on the student system, through the according settings windows as described in Section 3.6.4 for labels and in Section 3.6.5 for sketches. The settings made via the visibility window are global and, thus, override the individual settings.

3.6.7 Adjusting the View and Observing the Student

The teacher needs to be able to navigate within the virtual environment. He needs to adjust his viewport in order to focus on an area of interest and to observe the students behaviour. The base of the skull is a hollow space environment. The fully immersive student system is perfectly suitable for this scenario. The *zSpace*, however, constrains the view on the virtual environment to the frontal visual field. The *zSpace* is mainly used as desktop metaphor, where a virtual object is placed in front of the user. In the scenario of the skull, however, it is not enough to see what is in front of the teacher. He needs a 360° view.
Distinct problems arise with this. As the teacher is also placed within the hollow environment, thus, within the skull, he is not able to acquire an arbitrary distant overview on the scene, as this might lead to him exiting the hollow environment. This way, his view would be completely occluded. Usually, a *zSpace* application would let the user rotate and translate the objects in the environment itself. This approach is not useful in the hollow space application. A simple approach is implemented, to let the teacher rotate and translate its own view through moving the stylus. While pressing the left button of the stylus, the teacher's view is translated according to the the stylus movement. The view can be translated on all three axes. While pressing the right button of the stylus, the teacher's view is rotated around itself, allowing vertical rotation only to a maximum angle in order to prevent the teacher from having an upside down view.

Observing the Student

It can happen that the teacher loses track of the student. Especially if the student teleports, he can move instantly out of the viewport of the teacher. In order to be able to track the student at any time, the menu bar offers a button to focus on the student. The teachers view is translated so that he focuses on the student avatar.
Even if the student and teacher can see each others avatar, users still have difficulties in perceiving what the other sees [FBHH99]. This is why a *Student View Window* can be displayed. It shows the viewport of student, by adding a camera to the teacher system that moves according to the synchronized values of the student's head movement. This is an alternative approach to synchronizing a video stream of the student system output. It is not necessarily supported to synchronize video streams with a network connection. The alternative method reduces the synchronized information to merely the position and rotation of the students head. However, this only allows to briefly estimate what the student sees, as not synchronized interaction, such as the object inspection, can not be shown.

4. Implementation

This chapter briefly introduces the VR devices that are used for the realization of the presented approach as a prototype application (see Section 4.1). The *Unity* game engine is used for the implementation (see Section 4.2). Further, the networking functionality is discussed (seeSection 4.2.1).

4.1 Hardware

As fully immersive VR device for the student system the *HTC Vive* is used (see Section 4.1.1), while the semi-immersive teacher system will be implemented for the *zSpace* (see Section 4.1.2).

4.1.1 The HTC Vive

At the time of the prototype implementation, two major Virtual Reality headsets are available. The *HTC Vive* is superior to the *Oculus Rift* regarding the offered natural interaction possibilities, as it enables room-scale tracking of the user.
The standard setup of the *HTC Vive* comprises the headset, two motion controllers and two *lighthouse* tracking stations (see Figure 4.1)[1]. Each of the two OLED displays of the headset has a resolution of 1080 x 1200 pixels with a refreshing rate of 90 Hz. The headset offers a *field of view* of approximately 110° to achieve full immersion. The tracking is achieved through various sensors, such as gyroscope or accelerometer. Additionally, the two so-called *lighthose* cameras lighthouse base stations that emit pulses IR light are placed in two opposite corners of a room and roughly allow a 5m x 5m area of tracked movement. Further, two wireless 6-DOF motion controllers are also tracked by the system.

[1] https://www.vive.com/de/product/ (accessed: 31.05.2017)

4.1.2 The zSpace

The *zSpace* is a stereoscopic 3D monitor combined with headtracking and a stylus input device (see Figure 4.1)[2]. the user wears passive polarized 3D glasses that allow for the stereoscopic view. Headtracking is achieved through tracking the worn glasses with the infrared sensors at the top display frame. This setup corresponds to a so-called *Fishtank VR* [WAB93].
Further, a tracked stylus is provided that allows 6-DOF pen-based input.

Figure 4.1: Left: The components of the *HTC Vive* system. Right: The components of the *zSpace* system.

4.2 Unity

The *Unity*[3] game engine is frequently used in the development of Virtual Reality software. While primarily being use for video games, *Unity* targets not only common operating systems, mobile devices or latest gameing consoles. It also supports multiple Virtual Reality devices, as these become increasingly sought after in the field of gaming. While *Unity* offers an integration for the *HTC Vive* as well as for the *zSpace*, it is additionally a popular choice for prototype implementation, due to the editor that allows a fast implementation of first concepts.
The *HTC Vive*is natively supported through the *SteamVR* plugin[4], while the *zCore* plugin[5] offers support for the *zSpace*. Both offer access to all necessary functionality, such as motion tracking data, of the respective VR device, and only need to be imported into a *Unity* project.

4.2.1 Networking

As both VR systems are operation on different computers, these need to be connected via network. There are several possibilities to implement network functionality for a

[2] https://cdn.zspace.com/downloads/documentation/developer/zSpace_Developer_Intro_v1.0_rev1.2.pdf (accessed: 31.05.2017)
[3] https://unity3d.com/ (accessed: 31.05.2017)
[4] https://www.assetstore.unity3d.com/en/#!/content/32647 (accessed: 31.05.2017)
[5] http://developer.zspace.com/downloads (accessed: 31.05.2017)

Unity project. An approach is the *Virtual Reality Peripheral Network (VRPN)* is a specialised solution of network functionality targeted toward VR devices. It supports various different devices and is not *Unity*-dependet. Thus, is offers a great flexibility of extension. Further, *Unity* offers its own directly integrated multiplayer nework functionality. It has a high-level scripting API (HLAPI), that grants access to basic commands that cover most of the common requirements for multi-user application. Thus, the *Unity's* networking is a useful choice for prototyping purpuses, as a smooth integration into *Unity's* functionality is guaranteed.

4.2.2 Unity's Network System Concepts

A network application has one server and multiple clients. If there is no dedicated server, one client acts as a *host* and plays the role of both client the server (see Figure 4.2 [6]. In the case of the implemented prototype, the teacher system is the host, while the student system is a remote client.

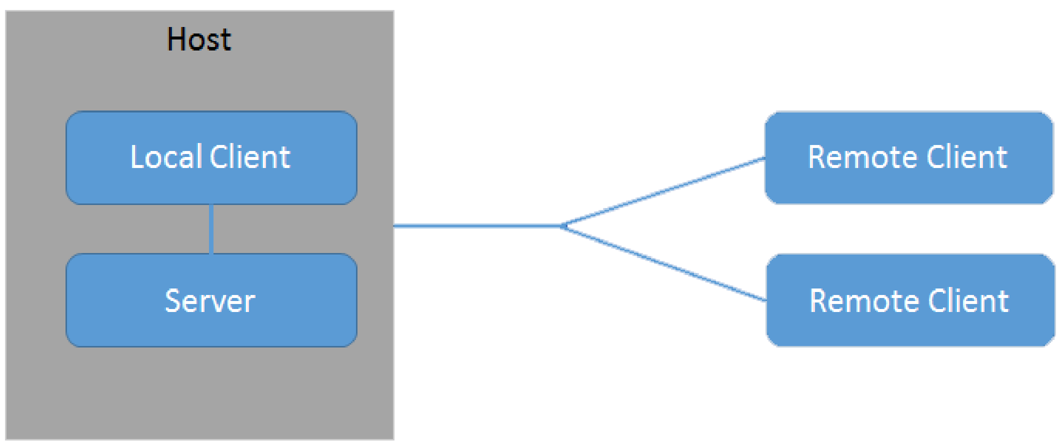

Figure 4.2: The diagram illustrates the concept of server, local client, and remote client.

Spawning Objects

The HLAPI proviedes a *Network Manager* that wraps up a lot of network functionality into a single place, such as spawning management. If an object shall be instantiated equally on every client, it must be *spawned* on the server. The server then causes the objects to be created on each connected client. Regarding the implemented prototype, there are the following kinds of *spawnable* objects: a landmark, a label or a 3D sketch. Each of them needs to be saved as a prefab that will be instantiated. Each spawnable object needs to be registered via the *Network Manager*.
Figure 4.3 [7] illustrates how information is being synchronized between the server and client. If a client wants a function to be run on the server he uses *commands*. The following code snippet shows a command to spawn a sketch prefab on the server.

[6] https://docs.unity3d.com/Manual/UNetConcepts.html (accessed: 31.05.2017)
[7] https://docs.unity3d.com/Manual/class-NetworkBehaviour.html (accessed: 31.05.2017)

```
[Command]
public void CmdSpawnSketch() {
        var sketch = (GameObject)Instantiate (sketchPrefab);
        NetworkServer.Spawn (sketch);
}
```

SyncVars are used to synchronize a state to the remote clients. The following code snippet shows, how syncvars can be used to synchronize the live sketching between the teacher and student system. While the teacher is sketching, the current position is set for syncvar *newPointPosition*. The syncvar hook is called on every client and adds the new point as new position to the sketch.

```
[SyncVar (hook = "AddPoint")]
public Vector3 newPointPosition;

public void AddPoint(Vector3 position) {
        if (sA == null) {
                sA = GetComponent<SketchedAnnotation>();
        }
        sA.AddNewPoint(position);
}
```

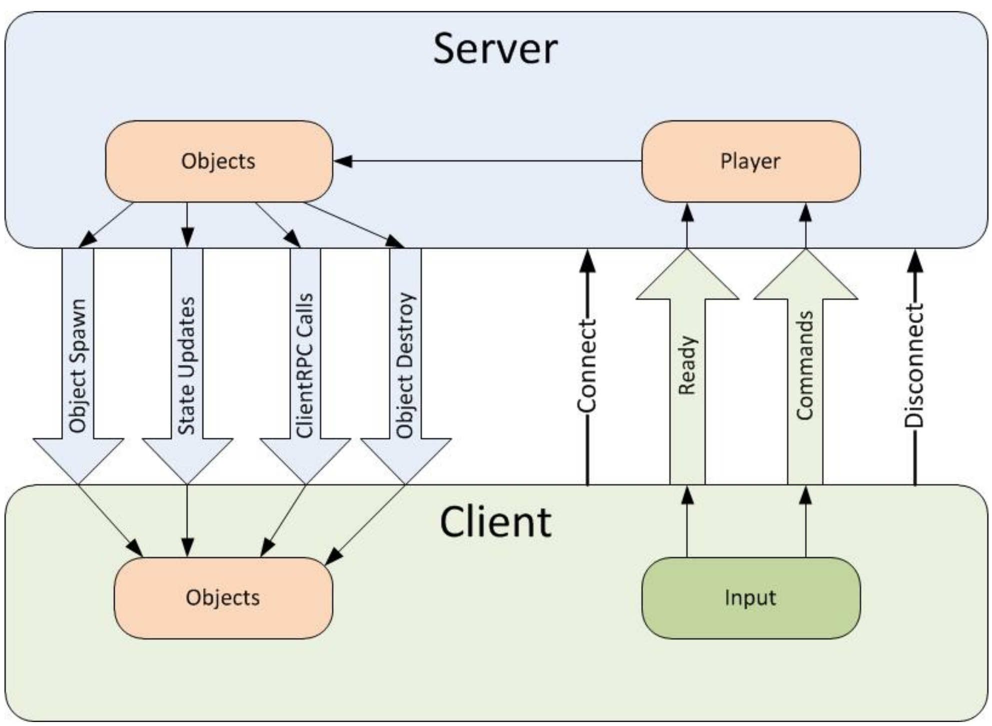

Figure 4.3: The diagram illustrates how information can be synchronized between the server and clients.

5. Evaluation

For both the student system and teacher system, an informal evaluation gives first impressions on usability issues and how the one-on-one tutoring approach helps to improve the VR experience of the student. The aim is to achieve qualitative results through letting the users think aloud, following the idea of [Nie12]. This method is ideally suitable for the tutoring system, as a verbal communication is an integral part of the scenario. After completing a series of tasks, the users are presented a questionnaire that addresses the requirements accumulated in Section 3.3. Both systems provide a variety of interaction possibilities. They are all being tested regarding usability but the main focus lies on the guided navigation, as the main motivation for the tutoring system is to support the student in avoiding unproductive paths.

The users are first presented the student system. The user study setup and results are discussed in Section 5.1. After completing the tasks on the student system, the users fill out the corresponding questionnaire. The user study of the teacher system follows afterwards and is described in Section 5.2. Hereby, the probands take advantage of the fact that they are already familiar with the basic functionality by having experienced it through the student system. The experience on the teacher system is also inquired through a questionnaire.
The questionnaires document a personal rating of the users through a 5-point Likert scale, to always allow a neutral rating. Even though such questionnaires enable a quantitative evaluation, the number of users that tested the system was too small to justify quantitative results. It is proposed to expand this evaluation to a larger number of probands, that involve people with a representative background for the application scenario. The users involved in the informal evaluation did not have a background in medicine. Especially the teacher system needs to still be evaluated through teaching staff in the field of anatomy.

5.1 A User Study for the Student System

In the preface of testing the student system, each proband provides information about his age and gender. Further, a proband is asked to rate his previous experience with VR, 3D input devices and 3D medical data. In order to keep the results of the user study comparable, each user tests the system following the same pattern. The process is is divided into three parts following by filling out a questionnaire:

Familiarization First, the user has time to familiarize with the virtual environment and the basic functionality. He is introduced to the concept of navigation within a drastically enlarged human skull model. Conforming the concept of the tutoring system, the instructions are given through verbal communication. The user is then introduced to the navigation concepts of *free flying* and the *teleport*. It is explained that he can always be positioned to a desired location by the instructor, if he loses orientation. This procedure is tested once with previous announcement. Further, it is explained to him that he can access information about different structures through pointing at them. The proband is further introduced to the *inspection mode*. He can try out these functionalities individually and is asked to inform the instructor as soon as he feels sufficiently familiarized with the controls. This phase of familiarization is not only important for learning the controls. For participants that never before experienced VR, the initial sensation about Virtual Reality may distract from the given task. Thus, some probands may need longer for familiarization.

Guiding The user is supposed to visit foramina of the base of skull, in order to learn about their location and acquire more information about them. For the test scenario, three foramina are chosen: the *Canalis opticus* (optical canal), the *Left Foramen Ovale* and the *Right Foramen Spinosum*. They vary in size and their location affords navigation between them. The order in which they have to be visited varies randomly between the probands.
A landmark is placed at the first foramina and the proband is asked to navigate to the marked location, following an arrow on his controller indicating the direction. the probands are free to decide which navigation method to use. As soon as the user arrives at the target location, the foramina is circled with the 3d Sketch input. The proband is introduced to the name of the structure while creating a label to annotate the foramina. This procedure is repeated for the other two structures.

Applying After the third structure has been examined, it is announced that the annotations are going to be hidden. The proband is then asked to navigate back to one of the previously shown structures. The foramina to navigate to is called by its previously introduced name and is randomly decided between the two choices.

Questionnaire After all tasks are finished, the proband fills out a questionnaire. The questions are derived from the requirement for the student system. For an evaluation of immersion within the student system, questions are taken from Witmer and Singer [WS98], who introduced ways to measure presence in virtual environments. Further, the questions focus mainly on the navitation tasks and orientation within the environment, but let the probands evaluate how helpful they felt each interaction was.

5.1.1 General Results

The student system was tested with six probands (5 male, 1 female) between the age of 22 and 31. Half of them had previously experienced VR applications. The other three, however, where familiar with 3D input devices through game consoles like the *Nintendo Wii*. None of the participants had a medical background. Thus, an evaluation with the target audience is still necessary to focus on the applicability for anatomy learning. Following, the results regarding immersion and usability of the different interaction methods are presented. The results on navigation are presented separately in the next section.

Immersion

The probands generally stated to have a strong sense of immersion, as they evaluated the interaction as very natural. Especially the position tracking which allows physical movement to be mapped directly to the virtual world was evaluated to highly contribute to a real-world feeling by a majority of the probands. One participant was even frightened at the first moment he looked down to the inner skull surface from his elevated position within the skull.
However, two participants missed an interaction method to be able to mark something on their own; a feature that is reserved for the teacher. They assumed, that the laser on the interaction controller acted as a pointer that would be synchronized with the teacher system. When asking questions about a structure they missed the control of pointing out a specific location. Such a lack of a desired control inhibits immersion.
Further, especially the live synchronization of the sketching notably fascinated the users, judging their immediate reactions. One participant remarked, regarding the live sketching, that he is now realizing, there is really another person involved.

Presentation of Text and Structures

The presentation of textual information was mainly evaluated positively. Every participant stated to easily understand what structures the information referred to. This comprised the *handbook* functionality, as well as the labels. As all participants lack a medical background, this result is, however, less meaningful, as they can hardly assess what information is important. Only one participant stated that he had problems reading texts, as he did not manage to adjust the HMD to achieve a sharp view and, thus, complained about blurry labels. Two probands where observed using the handbook feature excessively, instead of navigating towards the labels.
The drastically scaled skull model allowed the participants to have a detailed look on structures. However, the majority stated that they rather not feel able to project the acquired spacial knowledge to a smaller real-size model. While this is little surprising

for users without a medical background, this factor also needs to be evaluated within the target group of medical students. Being able to recognize structures within the scaled model does not necessarily imply that the knowledge can be transferred to the clearly smaller real skull. One of the participants, however, indicated that the 2D illustrations of hovered structures displayed in the handbook where very helpful.

Inspection of Single Structures

Only one of the participants used the inspection of a single structure again after the familiarization phase. A reason may be that the probands did not have a real interest in the specific structures, due to the missing medical background. Further, the clear focus on the navigation tasks may be the reason. The one person using the functionality was especially fascinated by taking the object along with him while continuing to navigate. The original structure, where the copy is taken from, is displayed semi-transparent, while the copy is active. This, however, provoked confusion instead of being helpful. Three participants articulated their confusion while trying out the feature during the familiarization phase. While highlighting the original object may usually be useful, this turns out to be problematic with the big and complex structures of the skull bones.

Easy to Learn Interface

The majority of the probands evaluated the displayed labels, attached to the controllers in order to explain the controls, as rather helpful. None of the participants displayed this help again after the familiarization phase. As they were still able to perform the demanded navigation tasks, the interface seems to be easily learnable. The questionnaire further confirmed this, as none of the students stated to be confused about the interaction.

5.1.2 Navigation Results

Improving the navigation, orientation and wayfinding within the student system through guidance, is the main focus of this evaluation. The according results are presentend:

Navigation Methods

After the different navigation concepts have been introduced, the probands where free to decide which of them they where using. It was noticeable that all of them mainly used the *free flying* navigation. Even though it was assumed that indicating the steering direction through the orientation of the controller might not be intuitive, every one of the participants rated this method intuitive. The easy adoption of navigation controls may be due to the wide distribution of 3D input devices in the field of gaming, known to every one of the participants.

The *teleport* technique, however, was rated as hard to access by half of the users. They generally did not like having to activate a specific interaction mode to access the teleport. Despite the large scale of the environment, a majority found the free navigation rather sufficient for the navigation tasks.

While the physical movement was much acclaimed by the majority and highly contributed to immersion, as stated above, one participant was noticeably cautious in using this method. While he did not trust the indicated barriers and was afraid of colliding with real world objects, he mainly stayed in one location throughout the guiding phase.

Orientation and Cybersickness

Another reason why the *teleport* function was sparsely used may be indicated by the evaluation of the feeling of disorientation. While none of the participants felt disoriented while freely navigating, each of them evaluated the teleport to cause at least a slight disorientation. An even higher rate of disorientation was linked to the process of the teacher altering the position of the user on the student system. This function was tested once in the familiarization face and was announced beforehand. A common reaction was, that the participants immediately tried to navigate back to the initial position, in order to orient themselves. The evaluation clearly shows that a direct cut to a new location has negative effects on the orientation. To cope with this, future researches might evaluate, if a transition of automated wayfinding can be helpful. This idea was excluded beforehand as a rise of cybersickness was assumed to come along with it. The evaluated navigation methods did not evoke cybersickness in any of the participants cases.

Wayfinding

The landmark as a hint for wayfinding was highly acclaimed by all participants. Everyone evaluated the landmark as very helpful. The guiding phase confirmed that following the direction indicated by the arrow on the interaction controller could be successfully performed by each participant. It did not matter if the target location was occluded by geometry. Notable, however, is that only one of the probands intentionally tried to fly through walls. Even though the walls are passable, all the other probands circumvented them.
Due to the landmark, the probands where able to perform the navigation tasks of the guiding phase sucessfully. After they were introduced to the three selected foramina, this knowledge should be applied through navigating to a previously visited location, without the guidance through the teacher system. Except one participant, they were all able to solve the task, but some stated through the questionnaire, that they felt unsure about being successful until the instructor confirmed the correct location. This result will, however, not be used to make any assumptions on a learning progress. It rather shows the difference of wayfinding when no indicator for guidance, such as the landmark, is used. The landmark lets the user follow a direct path to the target location. Without the landmark, the some of the probands navigated to a position that gives a broader overview over the environment in order to look for the destination. Even though the landmark approach may help finding a desired location faster, it may be worth evaluation through future research, if the landmark method will, on the other hand, hinder the users in building up a cognitive map of the environment, as few cognitive effort is demanded.

5.2 A User Study for the Teacher System

To evaluate the applicability of the tutoring system in a realistic anatomy teaching scenario, a formal evaluation including teaching staff and students would be required. As such an evaluation needs elaborate preparation, a lot of time and the right people at hand, an initial evaluation of the teacher system of the prototype will focus on usability aspects first. A questionnaire will be provided after completing several tasks. The questions are based on the usability aspects introduced in Section 2.3.5 and following a the scheme of [B+96].
The probands that finished the testing of the student system, will further participate in an evaluation of the teacher system. Here, it is of advantage that the probands are already familiar with concepts such as the landmark, sketching and label, as the target user of the teacher system will usually be instructed on how to use the system.

While a proband tests the teacher system, someone takes over the part of the student and simply moves around the environment spontaneously. The state of the student system is only partly relevant for the usability evaluation of the teacher system. It suffices to have have a randomly moving student avatar to follow. Each participant has to solve a sequence of the following selected main interaction tasks of the teacher system:

Window Handling The proband shall open the *Vive View* Window. He shall further drag it from the default top right position to the top left corner.

View Adjustment The view shall be adjusted through translation and rotation. The goal is to focus on an arbitrary foramina.

Landmark The user places a landmark on the surface. The landmark is placed again at another location.

3D Sketching Using the 3D sketching tool, the proband shall mark the focussed foramina through circling it. He shall adjust the color to another than the default one.

Reselection and Deleting The proband shall reselect the previously created sketch and delete it via the *3D Sketch* window.

Labelling A label shall be placed near the focussed foramina. An arbitrary text is typed in for the headline and description.

5.2.1 Results

Even though all of the participants where familiar with motion controllers like those of the *HTC Vive*, only one of them had previous experience with an equivalent device for a semi-immersive experience. However, all participants stated to have found it easy to understand the interaction technique that the stylus presents. This is not surprising,

as it combines natural pen-input with the previously experienced ray-casting method of the fully immersive system.
The users found the handling of the windows easily understandable, as the concept is already known through the common *WIMP* approach. They mainly enjoyed being able to reposition the windows individually.

The view adjustment was the big downside of the teacher system. None of the participants felt confident when translating or rotating the viewport. They felt it was cumbersome to use. This problem mainly arises due to the required 360° view, a scenario that is suboptimal for the *zSpace* system.

The 3D sketching was the most positively acclaimed interaction of the teacher system. The majority of the probands stated they would like to use this interaction technique frequently. It was obvious that several participants really had fun using this feature, as two of them asked to try this feature out again outside of the evaluation process. Half of the participants felt very confident using the system and one of them positively pointed out that he likes the mechanism to be able to directly draw onto surfaces. The other probands confidence was hampered through the inaccuracy of the stylus input. Indeed, occasionally jerking of the laser could be observed, even if the user held his hand still.
This jerking was even more prominent when trying to reselect the created sketch in order to delete it. The simple selection method through ray-casting is not suitable for the inaccuracies of the pen-input. Thus, the reselection of the sketch made the majority of the users feel not only not confident but also frustrated. As the general hand position to use the stylus does not necessarily allow the user to support his arm with the table, the inaccuracies seemed to increase with time.
The creation of labels came out neutral in the evaluation. While two participants found the positioning of the labels easy, while three users found the technique a bit too complex. Three participants felt that the text input through the keyboard was cumbersome, as the user has to switch between two input devices. One user, on the other hand, strongly appreciated the possibility for text input.

5.3 Promising Concepts and Suggested Improvements on Both Systems

The results for the student system were mainly positive. The users felt immersed in the virtual world and evaluated the interaction techniques as natural and intuitive. Especially the landmark turned out to be a great tool to guide the student to a specific location. The landmark concept might be an interesting field of investigation, in order to evaluate if it hinders the user to build up a cognitive map of the virtual environment, as it makes wayfinding very easy. Regarding the different navigation techniques, the teleport method was not able to convince the users. To improve the system that allows a quick and effective navigation within the virtual world, the possibility of transitions instead of a direct cut can be investigated.

While the student system mainly focuses on taking up an observer role instead of actively intervening in the virtual world, some users missed input possibilities. Especially a concept to let the student highlight a specific area in order to ease communication was demanded.

It was striking, that the semi-immersive *zSpace* had problems to fulfil some of the requirements for the teacher system. The device usually unfolds its potential when only one object of attention is the center of the scene. In the case of the tutoring system, however, the focus of attention is not on a single view direction. The *zSpace* as a *Fish Tank VR* system does not provide a natural input to achieve the needed 360° view. Instead of implementing an asymmetric approach with two different systems, it might be promising to develop a teacher-student system that makes use of two fully immersive devices. The much acclaimed 3D sketching should also be intuitively viable with the 6-DOF motion controllers. However, a solution for the the text input needed to be found.

Despite the downsides of the semi-immersive system, the evaluation showed that navigation tasks can be influenced positively through guiding a student in a shared virtual environment. Concepts like the landmark, might help to make VR learning more effective. Further, the feeling of immersion can be reinforced through another person sharing the virtual world. Here, specifically the live synchronization of the 3D sketching had a positive effect.

6. Conclusion

This thesis introduced an approach for a Virtual Reality one-on-one tutoring system to support anatomy education. A discussion about computer-based approaches that already augment medical curricula highlights the benefits of modern approaches compared to the traditional anatomy atlases and dissection. Current Virtual Reality technology offers new dimensions of exploring anatomy structures, but usually only provides a single user experience. The concept of shared virtual environments is introduced as a promising approach for VR learning applications.
A concept to let a medical student and a teacher share a VR experience for the purpose of education was developed for the human base of the skull as an application example. The main focus lay on the improvement of the student's navigation and the creation of annotations within the virtual world.

The approach of an asymmetric setting was realized as a prototype application, using the semi-immersive *zSpace* and the fully immersive *HTC Vive* that share a network connection. The focus was on guiding the student through the virtual world, in order to assure effective learning. In an informal evaluation the concept convinced with a *landmark* approach to improve the student's navigation towards a target location. Further, annotations in the form of labels and 3D sketches were an effective tool for the teacher to share information with the student. While these tools were evaluated to improve the VR experience for the student, a future formal analysis with the target audience (students and teaching staff involved in a medical curriculum) will be necessary, in order to evaluate the applicability of the system in the actual education context.

6.1 Future Work

Even though one-on-one tutoring is a very effective tool of instruction, it is not always applicable, due to a high number of educators needed. This is why a classroom setting is one common way of instruction. One teacher can address several students at the

same time. Therefore, possibilities to extend the presented approach to a classroom setting, could be an interesting topic for future research.
While the *zSpace* as a semi-immersive device had limitations regarding the navigation within the hollow space environment of the skull, the concept may be modified to serve another VR device for the teacher. A symmetric approach where both the student and teacher use a fully immersive device is promising direction to go.
The presented approach concentrated on dedicated input methods for the teacher, while the student's task was to navigate and observe. However, participants of the evaluation for the student system wished for more input possibilities. A future extension of the concept may be a sophisticated interaction technique that allows the student to point and mark specific locations within the environment.

Bibliography

[ASSW94] MJ Ackerman, VM Spitzer, AL Scherzinger, and DG Whitlock. The visible human data set: an image resource for anatomical visualization. *Medinfo. MEDINFO*, 8:1195–1198, 1994. (cited on Page 5)

[B+96] John Brooke et al. Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7, 1996. (cited on Page 56)

[BCW+06] Doug A Bowman, Jian Chen, Chadwick A Wingrave, John F Lucas, Andrew Ray, Nicholas F Polys, Qing Li, Yonca Haciahmetoglu, Ji-Sun Kim, Seonho Kim, et al. New directions in 3d user interfaces. *IJVR*, 5(2):3–14, 2006. (cited on Page 14 and 21)

[BDHB99] Doug A Bowman, Elizabeth T Davis, Larry F Hodges, and Albert N Badre. Maintaining spatial orientation during travel in an immersive virtual environment. *Presence: Teleoperators and Virtual Environments*, 8(6):618–631, 1999. (cited on Page 14)

[BGG03] Vicki Bruce, Patrick R Green, and Mark A Georgeson. *Visual perception: Physiology, psychology, & ecology*. Psychology Press, 2003. (cited on Page 8)

[BH97] Doug A Bowman and Larry F Hodges. An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments. In *Proceedings of the 1997 symposium on Interactive 3D graphics*, pages 35–ff. ACM, 1997. (cited on Page 17 and 18)

[BH99] Doug A Bowman and Larry F Hodges. Formalizing the design, evaluation, and application of interaction techniques for immersive virtual environments. *Journal of Visual Languages & Computing*, 10(1):37–53, 1999. (cited on Page vii, 17, 18, 22, and 31)

[BHB+07] Harry Brenton, Juan Hernandez, Fernando Bello, Paul Strutton, Sanjay Purkayastha, Tony Firth, and Ara Darzi. Using multimedia and web3d to enhance anatomy teaching. *Computers & Education*, 49(1):32–53, 2007. (cited on Page 3)

[BKLJP04] Doug Bowman, Ernst Kruijff, Joseph J LaViola Jr, and Ivan P Poupyrev. *3D User Interfaces: Theory and Practice*. Addison-Wesley, 2004. (cited on Page vii, 13, 14, 15, 16, 17, 18, and 19)

[Blo84] Benjamin S Bloom. The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational researcher*, 13(6):4–16, 1984. (cited on Page 13)

[BPT01] Christos Bouras, Alexandros Philopoulos, and Th Tsiatsos. e-learning through distributed virtual environments. *Journal of Network and Computer Applications*, 24(3):175–199, 2001. (cited on Page 11)

[Bri90] William Bricken. Learning in virtual reality. 1990. (cited on Page 10)

[Bro00] Judith R Brown. Enabling educational collaboration—a new shared reality. *Computers & Graphics*, 24(2):289–292, 2000. (cited on Page 11)

[CMRCL09] Gabriel Cirio, Maud Marchal, Tony Regia-Corte, and Anatole Lécuyer. The magic barrier tape: a novel metaphor for infinite navigation in virtual worlds with a restricted walking workspace. In *Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology*, pages 155–162. ACM, 2009. (cited on Page 15)

[CNSD93] Carolina Cruz-Neira, Daniel J Sandin, and Thomas A DeFanti. Surround-screen projection-based virtual reality: the design and implementation of the cave. In *Proceedings of the 20th annual conference on Computer graphics and interactive techniques*, pages 135–142. ACM, 1993. (cited on Page 10)

[Cun18] Daniel John Cunningham. *Cunningham's textbook of anatomy*. W. Wood, 1818. (cited on Page 24)

[DHB01] Parvati Dev, Edward P Hoffer, and G Octo Barnett. Computers in medical education. In *Medical informatics*, pages 610–637. Springer, 2001. (cited on Page 1, 11, and 13)

[EB16] Mohamed Estai and Stuart Bunt. Best teaching practices in anatomy education: A critical review. *Annals of Anatomy-Anatomischer Anzeiger*, 208:151–157, 2016. (cited on Page 4, 6, and 8)

[EM06] Martha Evens and Joel Michael. *One-on-one tutoring by humans and computers*. Psychology Press, 2006. (cited on Page 13)

[FBHH99] Mike Fraser, Steve Benford, Jon Hindmarsh, and Christian Heath. Supporting awareness and interaction through collaborative virtual interfaces.

In *Proceedings of the 12th annual ACM symposium on User interface software and technology*, pages 27–36. ACM, 1999. (cited on Page 15 and 46)

[FCD+10] Cédric Fleury, Alain Chauffaut, Thierry Duval, Valérie Gouranton, and Bruno Arnaldi. A generic model for embedding users' physical workspaces into multi-scale collaborative virtual environments. In *ICAT 2010 (20th International Conference on Artificial Reality and Telexistence)*, 2010. (cited on Page 15)

[Fei03] Alex Olwal Steven Feiner. The flexible pointer: An interaction technique for selection in augmented and virtual reality. In *Proc. UIST'03*, pages 81–82, 2003. (cited on Page 18)

[Ham82] William James Hamilton. *Textbook of human anatomy.* Springer, 1982. (cited on Page 24)

[HPP+96] Karl-Heinz Hohne, Bernhard Pflesser, Andreas Pommert, Martin Riemer, Thomas Schiemann, Rainer Schubert, and Ulf Tiede. A'virtual body'model for surgical education and rehearsal. *Computer*, 29(1):25–31, 1996. (cited on Page 4)

[HRL10] Hsiu-Mei Huang, Ulrich Rauch, and Shu-Sheng Liaw. Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, 55(3):1171–1182, 2010. (cited on Page 8 and 11)

[HS08] Kami Hanson and Brett E Shelton. Design and development of virtual reality: Analysis of challenges faced by educators. *Educational Technology & Society*, 11(1):118–131, 2008. (cited on Page 10)

[HV97] Helene Hoffman and Dzung Vu. Virtual reality: teaching tool of the twenty-first century?. *Academic Medicine*, 72(12):1076–81, 1997. (cited on Page 7, 9, and 11)

[JF00] Randolph L Jackson and Eileen Fagan. Collaboration and learning within immersive virtual reality. In *Proceedings of the third international conference on Collaborative virtual environments*, pages 83–92. ACM, 2000. (cited on Page 12)

[JRL+98] Andrew Johnson, Maria Roussos, Jason Leigh, Christina Vasilakis, Craig Barnes, and Thomas Moher. The nice project: Learning together in a virtual world. In *Virtual Reality Annual International Symposium, 1998. Proceedings., IEEE 1998*, pages 176–183. IEEE, 1998. (cited on Page 12)

[JS10] Joaquim Jorge and Faramarz Samavati. *Sketch-based interfaces and modeling.* Springer Science & Business Media, 2010. (cited on Page 20)

[JSM+14] Brett Jones, Rajinder Sodhi, Michael Murdock, Ravish Mehra, Hrvoje Benko, Andrew Wilson, Eyal Ofek, Blair MacIntyre, Nikunj Raghuvanshi, and Lior Shapira. Roomalive: magical experiences enabled by scalable, adaptive projector-camera units. In *Proceedings of the 27th annual ACM symposium on User interface software and technology*, pages 637–644. ACM, 2014. (cited on Page 10)

[JTW99] Randolph L Jackson, Wayne Taylor, and William Winn. Peer collaboration and virtual environments: a preliminary investigation of multi-participant virtual reality applied in science education. In *Proceedings of the 1999 ACM symposium on Applied computing*, pages 121–125. ACM, 1999. (cited on Page 12)

[KKP+00] Namgyu Kim, Gerard Jounghyun Kim, Chan-Mo Park, Inseok Lee, and Sung H Lim. Multimodal menu presentation and selection in immersive virtual environments. In *vr*, page 281, 2000. (cited on Page 18)

[KRHC15] Behrang Keshavarz, Bernhard E Riecke, Lawrence J Hettinger, and Jennifer L Campos. Vection and visually induced motion sickness: how are they related? *Frontiers in psychology*, 6:472, 2015. (cited on Page 16)

[LC00] Jeff Lander and GRAPHIC CONTENT. Shades of disney: Opaquing a 3d world. *Game Developer Magazine*, 7(3):15–20, 2000. (cited on Page 28)

[LC03] Wing Ho Leung and Tsuhan Chen. A multi-user 3-d virtual environment with interactive collaboration and shared whiteboard technologies. *Multimedia Tools and Applications*, 20(1):7–23, 2003. (cited on Page 12)

[LCDL+16] Morgan Le Chénéchal, Thierry Duval, Jérémy Lacoche, Valerie Gouranton, Jérôme Royan, and Bruno Arnaldi. When the giant meets the ant an asymmetric approach for collaborative object manipulation. In *3D User Interfaces (3DUI), 2016 IEEE Symposium on*, pages 277–278. IEEE, 2016. (cited on Page 12 and 25)

[LJ00] Joseph J LaViola Jr. A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin*, 32(1):47–56, 2000. (cited on Page 16)

[Min95] Mark R Mine. Virtual environment interaction techniques. *UNC Chapel Hill CS Dept*, 1995. (cited on Page 14, 15, 17, and 33)

[MJOG99] Tom Moher, Andrew Johnson, Stellan Ohlsson, and Mark Gillingham. Bridging strategies for vr-based learning. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, pages 536–543. ACM, 1999. (cited on Page 12)

[MN90] Rolf Molich and Jakob Nielsen. Improving a human-computer dialogue. *Communications of the ACM*, 33(3):338–348, 1990. (cited on Page 18 and 20)

[MNB14] Matjaž Mihelj, Domen Novak, and Samo Beguš. *Virtual reality technology and applications*. Springer, 2014. (cited on Page 8)

[MTM+16] Jacob Boesen Madsen, Markus Tatzqern, Claus B Madsen, Dieter Schmalstieg, and Denis Kalkofen. Temporal coherence strategies for augmented reality labeling. *IEEE transactions on visualization and computer graphics*, 22(4):1415–1423, 2016. (cited on Page 19)

[NCFD06] DT Nicholson, C Chalk, WRJ Funnell, and SJ Daniel. A randomized controlled study of a computer-generated three-dimensional model for teaching ear anatomy. *Med. Educ*, 40:1081–87, 2006. (cited on Page 6)

[Nie12] Jakob Nielsen. Thinking aloud: The# 1 usability tool. *Nielsen Norman Group [online]. January*, 16, 2012. (cited on Page 51)

[PBWI96] Ivan Poupyrev, Mark Billinghurst, Suzanne Weghorst, and Tadao Ichikawa. The go-go interaction technique: non-linear mapping for direct manipulation in vr. In *Proceedings of the 9th annual ACM symposium on User interface software and technology*, pages 79–80. ACM, 1996. (cited on Page 17)

[PIWB98] Ivan Poupyrev, T Ichikawa, S Weghorst, and M Billinghurst. Egocentric object manipulation in virtual environments: empirical evaluation of interaction techniques. In *Computer graphics forum*, volume 17, pages 41–52. Wiley Online Library, 1998. (cited on Page 17 and 18)

[PP00] Reinhard Putz and Reinhard Pabst. *Sobotta, Atlas of Human Anatomy Volume 1 - Head, Neck, Upper Limb*. 2000. (cited on Page vii, 5, 24, and 25)

[PPS99] Ian Pitt, Bernhard Preim, and Dipl-Inf Stefan Schlechtweg. An evaluation of interaction techniques for the exploration of 3d-illustrations. In *Software-Ergonomie'99*, pages 275–286. Springer, 1999. (cited on Page 5 and 26)

[PRS97] Bernhard Preim, Andreas Raab, and Thomas Strothotte. Coherent zooming of illustrations with 3d-graphics and text. In *Graphics Interface*, volume 97, pages 105–113, 1997. (cited on Page 5 and 19)

[Pso95] Joseph Psotka. Immersive training systems: Virtual reality and education and training. *Instructional science*, 23(5):405–431, 1995. (cited on Page 10, 11, and 12)

[RB75] James T Reason and Joseph John Brand. *Motion sickness.* Academic press, 1975. (cited on Page 16)

[RHWF06] Kai Riege, Thorsten Holtkamper, Gerold Wesche, and Bernd Frohlich. The bent pick ray: An extended pointing technique for multi-user interaction. In *3D User Interfaces, 2006. 3DUI 2006. IEEE Symposium on*, pages 62–65. IEEE, 2006. (cited on Page 18)

[RJSM93] JW Regian Jr, Wayne L Shebilske, and John M Monk. A preliminary empirical evaluation of virtual reality as a training tool for visual-spatial tasks. Technical report, DTIC Document, 1993. (cited on Page 11)

[Ros95] Cornelius Rosse. The potential of computerized representations of anatomy in the training of health care providers. *Academic Medicine*, 70(6):499–505, 1995. (cited on Page 4 and 7)

[Rot82] Scott D Roth. Ray casting for modeling solids. *Computer graphics and image processing*, 18(2):109–144, 1982. (cited on Page 17)

[RPDS00] Felix Ritter, Bernhard Preim, Oliver Deussen, and Thomas Strothotte. Using a 3d puzzle as a metaphor for learning spatial relations. In *Graphics Interface*, pages 171–178, 2000. (cited on Page 5)

[RSM92] JW Regian, Wayne L Shebilske, and John M Monk. Virtual reality: an instructional medium for visual-spatial tasks. *Journal of Communication*, 42(4):136–149, 1992. (cited on Page 10 and 11)

[SAK10] Kapil Sugand, Peter Abrahams, and Ashish Khurana. The anatomy of anatomy: a review for its modernization. *Anatomical sciences education*, 3(2):83–93, 2010. (cited on Page 1, 8, and 26)

[SBL+15] Patrick Saalfeld, Alexandra Baer, Kai Lawonn, Uta Preim, and Bernhard Preim. Das 3d user interface zspace. In *Bildverarbeitung für die Medizin 2015*, pages 83–88. Springer, 2015. (cited on Page 36)

[SBLJM13] Jonas Schild, Liane Bölicke, Joseph J LaViola Jr, and Maic Masuch. Creating and analyzing stereoscopic 3d graphical user interfaces in digital games. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 169–178. ACM, 2013. (cited on Page 19 and 37)

[SC02] William R Sherman and Alan B Craig. *Understanding virtual reality: Interface, application, and design.* Elsevier, 2002. (cited on Page 8)

[Sch83] Hendricus Gerard Schmidt. Problem-based learning: Rationale and description. *Medical education*, 17(1):11–16, 1983. (cited on Page 4)

[SCP95] Richard Stoakley, Matthew J Conway, and Randy Pausch. Virtual reality on a wim: interactive worlds in miniature. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 265–272. ACM Press/Addison-Wesley Publishing Co., 1995. (cited on Page 16 and 18)

[SGP15] Patrick Saalfeld, Sylvia Glaßer, and Bernhard Preim. 3d user interfaces for interactive annotation of vascular structures. In *Mensch & Computer*, pages 255–258, 2015. (cited on Page 19)

[SSPOJ16] P Saalfeld, Aleksandar Stojnic, B Preim, and S Oeltze-Jafra. Semi-immersive 3d sketching of vascular structures for medical education. In *Proc. of Eurographics Workshop on Visual Computing for Biology and Medicine (EG VCBM)*, pages 123–32, 2016. (cited on Page 20)

[Sta67] JA Starkweather. Computer-assisted learning in medical education. *Canadian Medical Association Journal*, 97(12):733, 1967. (cited on Page 7)

[TN02] Gustav Taxén and Ambjörn Naeve. A system for exploring open issues in vr-based education. *Computers & Graphics*, 26(4):593–598, 2002. (cited on Page 11 and 12)

[UAW+99] Martin Usoh, Kevin Arthur, Mary C Whitton, Rui Bastos, Anthony Steed, Mel Slater, and Frederick P Brooks Jr. Walking> walking-in-place> flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pages 359–364. ACM Press/Addison-Wesley Publishing Co., 1999. (cited on Page 15)

[WAB93] Colin Ware, Kevin Arthur, and Kellogg S Booth. Fish tank virtual reality. In *Proceedings of the INTERACT'93 and CHI'93 conference on Human factors in computing systems*, pages 37–42. ACM, 1993. (cited on Page 9, 10, and 48)

[WS98] Bob G Witmer and Michael J Singer. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments*, 7(3):225–240, 1998. (cited on Page 53)

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

Magdeburg, den *[. . .]*