Student and Teacher Meet in a Shared Virtual Reality:
A one-on-one Tutoring System for Anatomy Education

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Abstract
We introduce a Virtual Reality (VR) one-on-one tutoring system to support anatomy education. A student uses a fully immersive VR headset to explore the anatomy of the base of the human skull. A teacher guides the student by using the semi-immersive zSpace. Both systems are connected via network and each action is synchronized between both systems.
The teacher is provided with various features to direct the student through the immersive learning experience. The teacher can influence the student's navigation or provide annotations on the fly and hereby improve the student's learning experience.

CCS Concepts
• Human-centered computing → Interaction devices; Visualization; • Computing methodologies → Virtual reality;

1. Introduction

There exist a variety of methods to teach anatomy, comprising the use of anatomy atlases and dissections. These classical methods are complemented by computer-based systems that provide interactive 3D visualizations, motivating tasks and feedback [PS18]. Although existing VR applications enable students to freely explore a virtual environment at an individual pace, they may waste time following unproductive paths or may miss important details [DHB01]. In a *one-on-one tutoring* scenario, a teacher could give instructions on finding a specific structure and intervene if a student takes long in navigating.

Based on the Master's thesis by Schmeier [Sch17], we present a VR one-on-one tutoring system to provide a guided approach to anatomy education. The student uses a VR headset as it provides position tracking and 3D input devices, enabling them to interact naturally in the virtual world. For the teacher, however, a VR headset is not suitable, as the user's real environment is completely blocked. Therefore, we implemented the teacher system on a semi-immersive zSpace, i.e. a display that provides stereo rendering by wearing 3D glasses and motion parallax by tracking the user's head. The system is implemented using the *Unity* game engine.

2. Related Work

Human anatomy is a key aspect in medical education. Medical curricula target the understanding of anatomical structures, their form, position, size and their spatial relationships, e.g. which nerve supplies a particular muscle. The scientific study of anatomy covers different aspects, such as *gross anatomy* (the study of the structure and positioning of organs on a macroscopic level), which is the focus of this work. In the survey of Preim and Saalfeld, a wide variety of anatomy education systems are discussed [PS18].

Usually, VR 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]. 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.

Previous studies show that a collaboration between multiple learners in a shared immersive virtual environment can have a positive educational effect [JTW99, MJOG99, JF00]. 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. Tutoring describes a one-on-one dialogue between a teacher and a student with the purpose of helping the student to learn something [EM06]. Compared to other methods such as group instruction, tutoring is a much more effective way of learning [Blo84]. Computers can support one-on-one tutoring, delivering learning material appropriate for individual needs at "any time, any place, any pace" [DHB01].

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

In the following, the education scenario, medical scenario, student system and teacher system are described.

3.1. Education Scenario

The student explores a virtual anatomy model through a VR headset. As the student's real environment is completely blocked out, the teacher needs to join the virtual environment with the semi-immersive zSpace in order to guide the student. This approach corresponds with an asymmetric setting, similar to the work of Le Chénéchal et al. [LCDL*16], where two users use different hardware, navigation and manipulation techniques to interact with the virtual environment. The teacher should be able to navigate the student through the virtual world in order to find structures, and give explanations using annotations. To enable such a shared virtual environment, a network connection is necessary to synchronize information. Both teacher and student will be located in the same physical room while using the system.

Figure 1 illustrates this asymmetric setting and shows the initial position, orientation and corresponding view of both users.
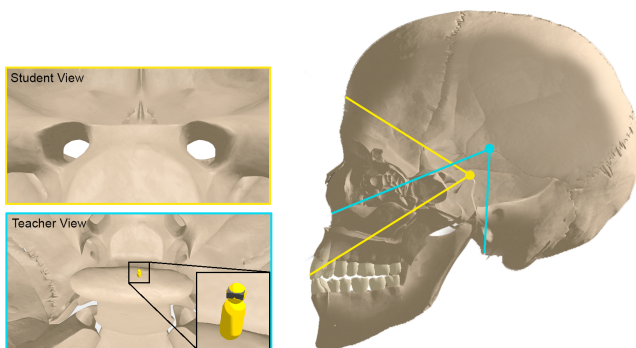
Figure 1: *Initial position, orientation and view of student and teacher within the virtual environment. The teacher view displays an avatar of the student.*

3.2. Medical Background on the Human Skull Base

The focus of this work is on gross anatomy and the human skull base. We interviewed an anatomist with 12 years of experience in teaching anatomy to obtain background information on the skull base as well as which aspects are the most important to learn. Learning the anatomy of the skull is an integral part of the anatomy curriculum. In illustrations, a consistent color scheme is used to distinguish arteries (red), veins (blue) and nerves (yellow).

The base of the human skull has several holes (foramina) through which arteries, veins and cranial nerves pass. An integral learning objective is to learn these foramina by their name and location, together with the structures that pass them.

3.3. Student System

First, we describe the requirements of the student's system followed by a description of its features.

3.3.1. Requirements

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 in the first years of study [SAK10]. This leads to the following requirements:

Immersion. Fully immersive VR interfaces are chosen as they enhance motivation and the feeling of immersion augments learning with experience [PS18].

Information is Directly Linked to Structures. To enhance learning, the student needs to develop a cognitive model of the anatomical structures. This is facilitated when the spatial and symbolic domain of information are linked appropriately. Therefore, 3D models should be augmented with their names and descriptions.

Natural and Intuitive Navigation without Disorientation. The student needs to be able to navigate through the virtual environment with minimal cognitive effort and without disorientation. Position tracking and motion controllers allow a natural and intuitive interface for this.

Inspection of Single Structures. Single structures, such as nerves, may be partly occluded by other structures. If the student wants to be able to inspect a structure closely, selection and manipulation techniques need to be implemented.

3.3.2. Realization

Since the student needs to recognize small anatomy details, an oversized skull model is placed 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.

The *HTC Vive* is chosen due to its room-scale position tracking capabilities and two six DOF controllers (see Fig. 2). Each of the two OLED displays of the headset has a resolution of 1080×1200 pixels with a refresh 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 and two *lighthouse* base stations that emit pulses of infrared light. This roughly allows a 5 m × 5 m area of tracked movement. The *HTC Vive* is supported in the Unity game engine through the *SteamVR* plugin.

Figure 2: *Left: the HTC Vive system. Right: the zSpace system.*

User Interface. The controller of the non-dominant hand is the *Menu Controller* and the controller of the dominant hand is the *Interaction Controller*. The menu is attached on top of it. 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 shows the three menu pages *handbook*, *navigation* and *inspect*.


Figure 3: *The three menu pages of the student system, where each represents a different interaction mode: left – handbook, middle – navigation, right – inspect.*

The handbook is the default mode when the system is started and assists the student in exploring the virtual world. Whenever the ray hits a sub-structure of the human skull base, its name, a short description or a 2D illustration is shown (see Fig. 3, left).

The navigation menu offers three different ways for navigation:

- physical walking,
- free flying corresponding to a *flying carpet* metaphor where the student flies in the pointing direction of the *Interaction Controller*, and
- teleportation, where the student can either directly jump to a landmark that was defined by the teacher or teleport to an area that is chosen by the student via pointing and selecting with a beam (see Fig. 4). The length of this beam can be adjusted by swiping on the touchpad of the interaction controller.
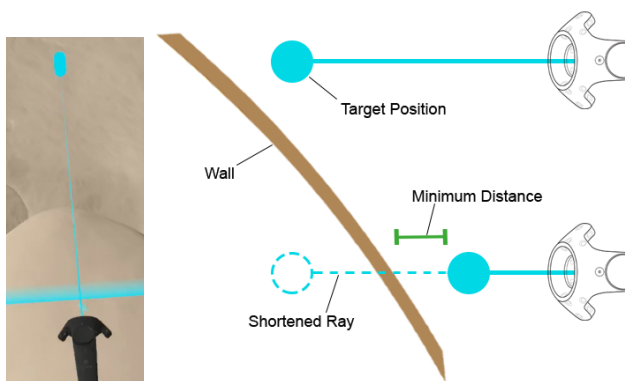
Figure 4: *Left: the adjustable ray for teleporting shows the target location through a capsule at the tip. Right: in order to avoid teleporting through a wall, the teleportation ray is shortened until there is a minimum distance between the wall and the target location.*

The *Interaction Controller* enables selection through ray-casting and is used for precision tasks such as pointing and selecting. A laser beam originates from the controller and follows its pointing direction. The first selectable object that the ray hits is highlighted. The trigger on the back of the controller is used to select the object.

Due to the large scale of the skull base, the student may have difficulties to get a full image of single structures. For this, the third page of the menu controller (the inspect mode) can be activated. Here, the student can select single structures. After selection, a ghost copy [TRC01] of the structure is placed within the student's reach, while the original structure is displayed highlighted (see Fig. 5). The student can use both controllers to grab and manipulate the structure directly with the virtual hand method [RH92] which resembles real world interaction with an object.
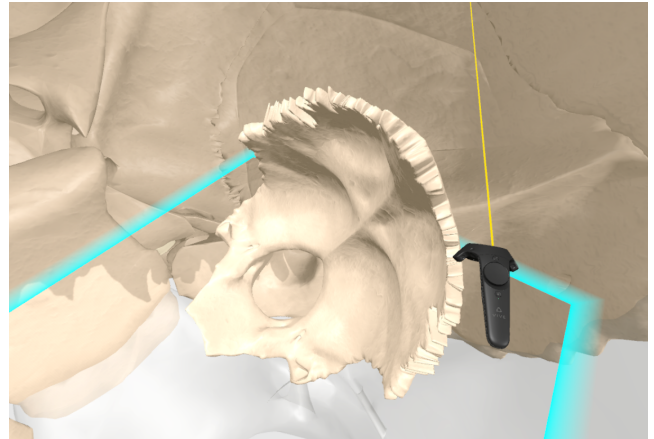
Figure 5: *A smaller copy of a selected skull bone can be inspected closely. The original structure is shown semi-transparently in the background.*

3.4. Teacher System

First, we describe the requirements of the teacher's system followed by a description of its features.

3.4.1. Requirements

The target group for the teacher system consists 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. Based on the student system, 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 familiar with the anatomy of the human base of the skull, the benefits of full immersion are less important. Instead, the teacher might need to have access to prepared notes or a keyboard for text input. This makes a semi-immersive system appropriate.

Support the Student's Navigation. 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 at the according location on the teacher's system. Furthermore, a possibility to hint the student to some location or alter the position completely is needed.

Provide Annotations for the Student. The creation of content for

the symbolic domain has do be provided at run time. Textual input is best suited for annotations of names and descriptions. The spatial and symbolic domain can be linked effectively with labels. If the teacher wants to highlight a certain area or illustrate concepts, a free-form 3D sketching tool is appropriate.

3.4.2. Realization

The teacher takes an *overview position* within the environment and looks down at the student in order to follow their position and orientation. The student is represented as a simplified avatar on the teacher system in order to contrast with the environment (see Fig. 1). This way, the teacher can track the student's position and orientation. The teacher, on the other hand, is not represented in the student system.

In our application, we use the *zSpace* as a semi-immersive device that combines a stereoscopic display with head tracking (so-called *Fish Tank VR* [WAB93], see Fig. 2). Further, it provides a stylus as a six DOF pen-based input device, which is especially suited for the required 3D sketch input. This device was already used for anatomy education, i.e. the *Visible Body* platform employed its benefit and Saalfeld et al. [SSPOJ16] used it to sketch complex vascular structures.

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

User Interface and Stylus Interaction Following an analysis of 3D user interfaces for stereoscopic devices from Schild et al. [SBLJM13], a *view-fixed* interface is chosen. It is always rendered on top of the scene so that it cannot be occluded by the 3D environment. Figure 6, left, shows the menu bar attached to the bottom display frame of the *zSpace*.

Figure 6: *Left: the view-fixed user interface of the semi-immersive teacher system. From left to right: label mode, 3D sketch mode, landmark mode, center view on student, show student's view, show/hide annotations, help. Right: the help menu shows the button layout of the zSpace's stylus.*

The stylus can be used for pointing tasks with ray casting. The stylus offers three input buttons, where the primary button controls different functionality based on the current mode. The secondary and tertiary button enable the teacher to adjust the view (in Figure 6, right, the help window with the button assignment is shown). While pressing the left button of the stylus, the teacher's view can be translated on all three axes according to the stylus movement. While pressing the right button, the teacher's view is rotated around itself. Usually, the length of the laser beam is determined by the object that is hit. However, depending on the mode of interaction, the laser may have a predefined length, e.g., in the *3D Sketch* mode.

Guiding the Student's Navigation The teacher system offers two different approaches to guide the student. The teacher may indirectly lead the student to a desired location through placing a landmark at the target position (see Fig. 7). To place a landmark into the environment, the teacher needs to activate the *Landmark Interaction Mode*. As interesting positions usually lie on a surface of a structure, the landmark position can be set via ray casting onto the 3D model of the skull base. After that, an arrow is placed at the student's controller facing into the direction of the landmark (see Fig. 7).
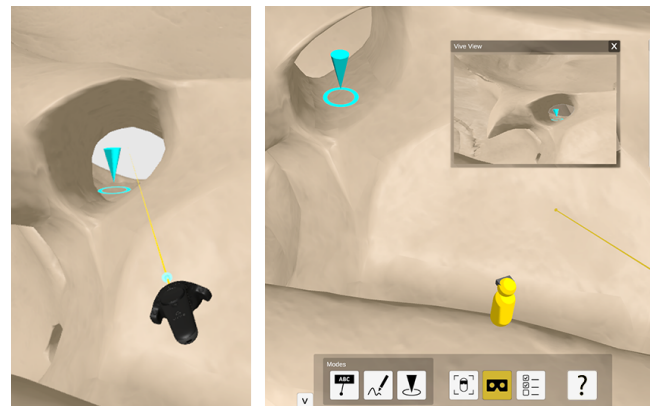

Figure 7: *Left: The student's view on a landmark. Right: The corresponding view on the teacher system. The student's avatar can be seen, looking right at the landmark. The teacher can see the student's view with an extra window at the top right.*

Even though the landmark can lead the student to a desired location, it can still be helpful to actively change the student's position. To re-position the student, the teacher can *pick up* the student's avatar with the stylus and release it somewhere else. Only the target position is synchronized to the student's systems to prevent cybersickness by getting moved around.

Creating Labels For the creation of labels, we follow Pick et al. [PWHK16] who present a workflow to create, review and modify labels in VR. Labels can only be positioned on a surface in order to assure a direct link between object and information. The creation of a label is realized in three steps (see Fig. 8). After raycasting onto the desired position of the label starting point, the teacher presses the primary button, creates a label and drags it to the desired location in the 3D space. Labels are always facing the student, thus, their orientation does not have to be defined by the teacher.

Creating 3D Sketched Annotations A dedicated input technique is provided for the teacher to allow them to draw structures such as vessels and nerves freely in 3D space to create 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 color palette and two different brush sizes (see Fig. 9). Furthermore, the laser beam is set to a predefined length to allow the teacher to sketch in mid-air. If the beam hits a surface, it is shortened to lie on the surface. During pressing the primary button,
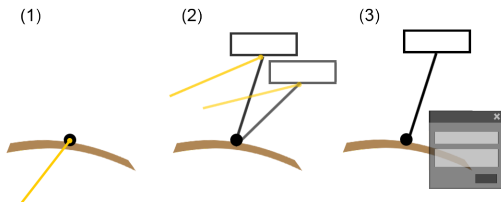
Figure 8: *Labels can be created by (1) ray-casting onto the surface, (2) dragging the label to the desired location and (3) edit its content within an extra window.*
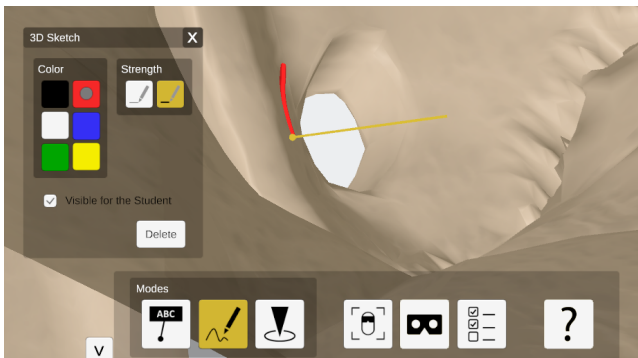
Figure 9: *The 3D Sketch Mode is active. The window comprising sketch settings is opened while a red stroke is sketched directly onto the surface.*

the sketch is created at the laser beam tip and continuously synchronized with the student system. The teacher draws a centerline which is enclosed by a 3D tube during sketching.

4. Summary & Conclusion

We introduced an approach for a VR one-on-one tutoring system to support anatomy education. Current VR technology offers new dimensions of exploring anatomy structures, but usually only provides a single user experience. We presented a shared virtual environment where guidance from a teacher is provided. An asymmetric setting was realized, using the semi-immersive *zSpace* and the fully immersive *HTC Vive* that share a network connection.

Even though one-on-one tutoring is an effective tool of instruction, it is not always applicable, due to a high number of educators needed. Therefore, possibilities to extend the presented approach to a classroom setting, where the teacher guides several students, is an interesting topic for future research. Another way to reach more students in one teaching session is by integrating a possibility for remote collaboration where the students can be at different physical locations.

In order to evaluate the applicability of the system in the education context, a future formal analysis with the target audience (students and teaching staff involved in a medical curriculum) is necessary. The evaluation of navigation techniques should include an assessment how well they support or prevent building up a men-

tal map of the environment, which could be an important indicator for the learning outcome.

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