Preliminary Findings from a Pilot Study on Teaching Medical Undergraduate Students Integrating Virtual Anatomy

Abstract. This paper outlines the implementation process and pilot trial on a teaching project entitled "Virtual Anatomy", developed by two Medical University institutions based in Austria. This project addressed contemporary challenges in traditional anatomy teaching, such as resource intensity as well as space and time constraints in the dissection environment, by introducing three virtual teaching scenarios: Live-rendered 3D models of clinical imaging using the Cinematic Rendering technology, 3D live camera visualization of anatomic preparations, and high-fidelity 3D scans of wax and tissue models accessible via a web browser technology. The project aimed to enhance traditional anatomy teaching by providing an optimized spatial understanding of morphological structures prior to the students entering their dissection practical, while accommodating large student groups of 500+ participants. The implementation included installing a large 7x4-m LED wall with 3D support in the lecture hall, where students used active shutter glasses for simultaneous 3D visualization on two different campuses. More than 170 anatomical models were digitized and made available through Moodle. The system was rolled out in September 2024. Successful trials with 500 undergraduate students in October 2024 were immediately transformed into a full-scale implementation during the pilot phase. Initial evaluations on student experience were promising, yielding the opportunity to implement virtual anatomy to other medical institutions. In this paper we summarize the initial experiences, evaluation and findings of the pilot.

Keywords: 3D lecture, active shutter, 3D objects, 3D teaching, 3D live transmission, 3D visualization, LED wall, virtual anatomy.

1 Introduction

Anatomy teaching forms a fundamental pillar for the education of undergraduate students in medicine. However, teaching anatomy based on human tissues is a resource and personnel intense task. It involves complex logistics for the provision and maintenance of human tissues and likewise requires a costly infrastructure for storage and preparation. Anatomy teaching facilities such as dissection rooms require expensive equipment and are limited in space and availability. Therefore, the number of students participating in practical dissection courses is limited. In a number of cases, the student cohort commencing medical school has to be divided into many subgroups so to be taught separately. Since the anatomy lectures are faced time constraints in the curriculum, this causes a severe time restriction for each group to participate in person in the dissection room. Therefore, as the objective is to prepare students in a best possible way for them to gain a maximum of hands-on experience during the dissection lectures.

For this purpose, theoretical lectures students receive in advance need to be optimized for the students to achieve their learning outcomes. To prepare students in a most efficient manner for their practical dissection courses, preexisting classical Power-Point based 2D lectures were modified and enhanced by the usage of virtual tools.

Though virtual tools so far fail to replace hands-on training in the dissection room environment for numerous reasons, they may facilitate a realistic spatial learning experience to enhance the learning process of medical students. Virtual 3D technology is said to help recent student cohorts to better identify the regional anatomy of organs, neurovascular pathways or other important anatomical structures within prosections or dissections. This knowledge is highly important during the practical dissection lectures, where the students will experience the real life haptic, spatial and procedural steps necessary in medical education. Hence one, of our main hypotheses for this given project was that theoretical lectures enriched with 3D virtual tools prepare students much better for practical dissection courses in the way that they better remember anatomical structures than they would do with traditional 2D content.

2 Overall didactical approach and research hypotheses

In 2022, a ministry funded research and teaching development project entitled “Virtual Anatomy” was initiated together with our partner institution, the Medical Faculty of the Johannes Kepler University in Linz, Austria [5]. The project rollout commenced, defining multidimensional use cases and user requirements [6], considering the major stakeholders. In parallel, a technical criteria list was created. Based on the outcomes of the use cases, a holistic approach was defined with three virtual teaching scenarios covering the given use cases and user requirements as well as fulfilling the technical criteria list as much as possible. Two virtual teaching scenarios involved the use of 3D technology in a large lecture room (500+ students) setting. One scenario involved the 3D representation of anatomical models which can be studied on demand by the students remote. Two didactic scenarios were designed for an instruction-driven study, and one for both –lecturer and student driven, and for teaching large cohorts (500+) of students.

The following research hypotheses and goals were defined for the given approach:

- Spatial display of tissue prosections and models help facilitate students to better understand tissue morphology.
- Students observe added value of 3D visualization when compared to conventional 2D images.
- Virtual 3D teaching is superior in preparing undergraduate students for their hands-on dissection course.
- Virtual anatomy increases the interest of medical undergraduate students in anatomy.
- 3D presentations help students to better achieve their learning goals.

This paper outlines the design process for the virtual tools finally being used, introduces the pre-defined teaching scenarios and further details on the technical implementation. Finally, we will share experiences and evaluation results from our first pilot trial on our research goals and hypotheses, which we performed in winter semester 2024/2025 at our university.

3 State of the Art

According to the market research we performed, the system we built up at our side and which is described in this research paper is unique. A comparable installation can only be found at our partner university in Linz, with whom we worked closely together in this project. The installation at our university differs by the components of the 3D LED wall and the 3D live camera. Both are cutting edge technologies which do exist for a very short time on the market. The 3D camera rig was specifically built for us, there is only one by us known company world wide which can produce them.

In terms of technology, virtual reality tools have not proven a suitable option to fulfill the needs of contemporary gross anatomy teaching in the Central European setting. As scenarios in which student cohorts of 500+ needed to be addressed, virtual or augmented reality did not offer affordable scaling. In the here implemented scenarios, a stereoscopic live view of tissues and a special 3D rendering technique was deployed, which so far had only been used at the partner university [15], was offered.

The research project nARvibrain [8], performed in a collaboration between Medical University of Graz, the University of Applied Sciences FH Joanneum in Austria and the company Risc Software GmbH aimed to detect brain tumors by combining of augmented reality technology, artificial intelligence and radiology. The aim was a holistic representation of a patient including all relevant image data results. Again, the use case is very different from our requirements, by putting the focus on assistance of medical doctors rather than on undergraduate education. Also, this option required hardware which would have been unaffordable for 500+ students in parallel.

The platform Anatomyka [13] provides apps for iOS and Android capable of displaying more than 13.000 already annotated anatomical objects, but does not allow to add own objects or annotations and also provides no stereoscopic viewing. However, this was an obligatory criterion for our teaching scenario #3.

There also exist a number of medical simulation programs including HoloScenarios developed by the simulation company GigXR [14] in collaboration with the Cambridge University hospitals. This software provides a realistic simulation of the entire patient care journey, but there is no direct connection to anatomy in education. Hence this software appeared more suitable for master students who are already in their clinical years. For the 3D representation of anatomical models we assessed a number of platforms capable of viewing and distributing 3D objects, including Online 3D viewer [9], 3D Vault [10], CG Trader [11], Visibly Body [12] and Sketchfab [17]. Sketchfab offered all features we need, including an easy-to-use annotation interface for lecturers, a cloud-based upload for new objects, an embedded code which allows seamless integration in our learning management system Moodle and privacy settings. Furthermore, it offers affordable pricing for academic institutions. The other solutions were either too costly, failed offering the addition of own objects and/or annotation of them, or failed providing a protected access link to the objects.

4 Technical Implementation

In this chapter we describe the design and technical implementation of our three teaching scenarios.

Teaching scenario #1 - “live-rendered 3D models of clinical imaging scans” - utilizes the Cinematic Rendering, a technology for photorealistic imaging based post-processed volumetric medical imaging data [3] with a commercial rendering software [4] and a stereoscopic 3D visualization technology installed in our huge lecture room. Teaching scenario #2 - “3D live camera and 3D transmission” – enables the 3D live visualization of anatomical prosections demonstrated and instructed by the lecturers on a huge LED wall. Teaching scenario #3 - “3D scanning of anatomical models” – utilizes 3D scans of anatomical (wax, plaster, cast) models, plastinates or prosections preselected by the anatomy team. Students can observe and study them from home without the necessity to attend the university physically. This approach was intended to offer the students flexibility, while addressing space and time constraints to visit the study room.

Technically speaking this excluded for us the implementation of virtual reality technology in scenarios #1 and #2 due to the high-cost factor. An instructor-driven scenario was preferred over a student driven one. Scenario #3 can be student driven or teacher driven, hence the 3D models can be shown and explained in the lecture room by a teacher as well as they can be used for self directed study by students afterwards. Therefore, the chosen approach could be accessed easily with a standard web browser and internet connection by students without the need of costly 3D technology and equipment.

Didactically the integration of the virtual scenarios #1 and #2 into teaching was supported by visual uses cases which helped the lecturers to transform parts of the current 2D lectures into 3D lectures [7]. The planning for the winter semester was finalized until September 2024.

The technical installation was completed in September 2024, first live transmissions and networked lectures with our partner university were performed in the same month. In October 2024 a pilot trial began by integrating the virtual anatomy into the teaching process of our undergraduate medical students. This pilot trial was accompanied by an evaluation based on a questionnaire developed by us for this special purpose.

4.1 Virtual 3D scenario #1: “live rendered stereoscopic models of MRI scans”

This scenario is set up as a networked scenario between our university and our partner university in Linz. The core technology is a special 3D software [16] which allows to render the exploring of MRI models in photo realistic stereoscopic view in real time. After a one-time preparation phase models can be navigated by a lecturer using a simple x-box controller and viewed in real time. The technology allows to view all relevant layers of a human body such as bones, veins or muscles.

For stereo 3D visualization we chose in scenarios #1 and #2 a 7.3 x 4 m LED wall with a 1.9 mm pixel pitch, full 3D support and low-power technology in the large lecture hall. The LED wall - and all of the devices and players – had to be able to display a native 4K UHD signal at 3840x2160@60Hz. To optimize the stereoscopic display, we

synchronized all of the sources by means of a central clock. Displaying 3D images required fully retaining resolution and brightness with loss-free, synchronous transmission and identical latency. Owing to the flip-chip surface mounted device (SMD) technology, the direct view LED modules (dvLED) used require around 60 percent less power than conventional indoor LED installations. Their heat development was also minimized, which in turn reduced the need for additional air conditioning and contributes to the durability of the display. The video wall delivers an excellent contrast ratio of up to 8000:1 and a deep black level. With a luminosity of up to 700 candela per square meter, the content is shown to its best advantage even in the most varied lighting conditions, and optimally presented to students as visualized in **Fig. 1**.
The stereoscopic visualization in the lecture room is achieved by active shutter glasses with infrared receivers worn by all participants. Even though the logistics handling up to 500 glasses was a challenge we could solve this problem by appropriate technology capable of charging 500+ devices in parallel and two disinfection conveyer belts. This is accompanied by a self developed logistic concept to effectively distribute and collect the glasses before and after the lectures.

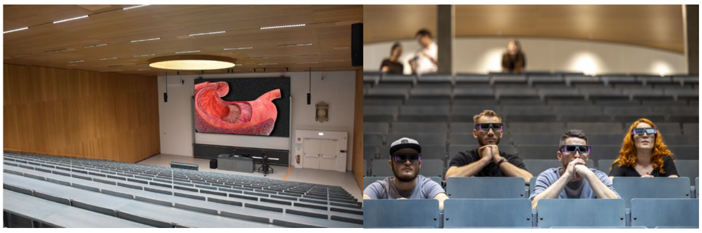

Fig. 1. Stereoscopic life rendered MRI model of a stomach displayed on our LED wall in the big anatomy lecture room and students wearing active shutter glasses

4.2 Virtual 3D teaching scenario #2: "Stereoscopic live camera and 3D transmission"

This scenario demonstrates anatomical structures to large student groups (500+) using a 3D camera that displays tissues live and stereoscopically on a 3D LED wall. Students in the back rows can see tissues in full scale and detail, with stereoscopic viewing providing spatial dimensions crucial for later dissection exercises. The system extends to our partner university in Linz via real-time 3D transmission of two synchronized 4K streams over the Internet, achieving approximately 200ms delay through frame sequential transmission that maintains synchronicity while reducing frequency from 60Hz to 30Hz.

The stereoscopic camera uses mirror rig technology rather than side-by-side cameras, allowing closer positioning (~30cm versus 1m minimum) to capture small anatomical structures. Our Stereotec camera rig [20] – see also **Fig. 2** - features two synchronized 4K cameras with remote focus and aperture control, though zooming is not supported due to space constraints of the lenses. A programmable shading panel manages synchronous and/or separate camera settings. The system routes feeds through 12G-to-fiber converters to a matrix mixer that distributes signals to both the LED wall and encoding computer for real-time transmission to Linz.

For scenario #1 and #2 we furthermore offer 2D streaming for students attending remotely (enabling hybrid teaching – see [2]), accommodating bandwidth limitations and avoiding expensive 3D infrastructure at home while providing zoom functionality which is unavailable in the live 3D presentations.

Fig. 2. Left the 3D mirror rig camera – Right active shutter glasses for stereoscopic view

4.3 Virtual 3D teaching scenario #3: "3D scanning & access of anatomical models"

This scenario enables students to access and manipulate annotated 3D anatomical scans through a standard web browser from any location with an internet connection. For scenario #3, we have scanned so far over 170 anatomical specimens including wax models, bones, and plastinates using two different 3D scanning technologies.

We used both, a handheld 3D scanner with blue LED technology [18] and a custom-built 3D scan box developed by ACMIT [19] as it can be seen in **Fig. 3**. The scan box utilizes photogrammetry, allowing for superior quality and faster scanning of objects up to the size of a human skull due to its fixed camera system and internal scanning environment.

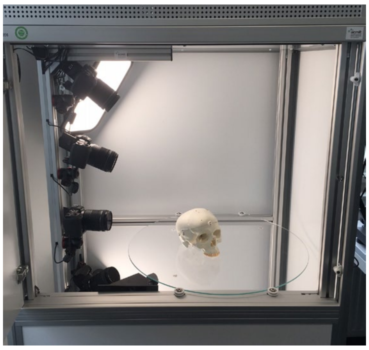

Fig. 3. Photo box 3D scanner

During the scanning process, we encountered significant challenges unlike those typically faced in industrial scanning applications. While mechanical and automotive industries generally scan objects with consistent surfaces, anatomical preparations present complex surfaces that are neither uniformly smooth nor structured, often featuring

deep recesses and glossy areas. Addressing these technical challenges required substantial practical expertise and specialized techniques, including reference cubes, customized camera settings, and post-processing methods. The size variation of specimens also presented difficulties, particularly with extremely small or thin anatomical features such as arteries and veins.
Following scanning, we selected an appropriate cloud-based platform for annotation. We chose Sketchfab for its generous upload capacity, extensive editing capabilities, annotation functionality, embedding options, and robust privacy settings. Currently, our platform houses 170 models across all categories (wax models, bones, plastinates, and formalin-fixed specimens). Some examples are shown in **Fig. 4**. These scans are currently annotated by lecturers and linked in our Moodle platform for the students.

Fig. 4. 3D scans of full brain, hemisphere with visible fibre tracts and a bone (sacrum)

5 Evaluation

With winter semester 2024/25 we started with a pilot trial of our virtual anatomy. 10 lectures of the anatomy module "Intestines and conduits" have been adopted by the lecturers to use the teaching scenario #2: "Stereoscopic live camera" locally in our big lecture room with 500+ students. This process was technically and organizationally supported by (visual) use cases [7]. After the 10 lessons we started an evaluation in order to see how well we met our research hypotheses defined in section 2.

5.1 Design of the questionnaire

The first step of the evaluation was the design of an appropriate questionnaire. Together with our anatomy teachers we discussed which output we want to have and ended up with a questionnaire which covered five main areas: pre-existing knowledge with 3D, anatomy content related questions in order to prove/disprove our research hypotheses, presence and usability.
With the area of pre-existing 3D knowledge, we wanted to check whether our students have already 3D experience, e.g. from gaming or from using virtual reality tools. The presence section covered questions how well our virtual tools helped them to make a seamless transition from the reality to the 3D world, hence have the feeling of being an integral part of the 3D world. The last area covered usability questions in terms of how easy the tools could be used.
All in all, we had 28 closed questions and two open questions, where students could tell us about technical problems they encountered and give us recommendations for improvements.

5.2 Results

The evaluation was started online after the last lecture with the 3D camera amongst 513 students and open for two weeks with one reminder in between. We received 72 filled in forms, which corresponds to a return rate of 14%. Even though the return rate is very low it goes inline with the number of students being present at the lectures. Since participation at these lectures was voluntary, only about 50 students were present in average at the lectures. Since we explicitly asked the students only to return the questionnaire in case, they have at least attended one of the 10 lectures, the actual return rate is much higher but not exactly calculable. 38.9% of the responses resulted from female students, 61.1% from male students. 95.8% of the students were between 18 and 25 years old, 4.2% between 26 and 35.

In the section pre-existing knowledge we received the results as given in **Fig. 5**. In summary it can be stated that about 37% of the students had existing experience with 3D games or technologies so far. More than 88% stated that their spatial vision is not impaired in everyday life and about 78% are not exhausted by 3D projections. These results are a good base for our virtual 3D teaching scenarios because they suggest that the majority of students has no major problems with stereoscopic 3D.

Fig. 5. Detailed evaluation results of section pre-existing knowledge

The results with regards to our research hypotheses as stated in section 2 are given in **Fig. 6**. From these results it can be derived that spatial display of anatomical preparations helps ~89% of the students to better understand anatomical structures. ~92% of the students see a clear added value of 3D visualization in comparison to conventional 2D images.

An impressing majority of ~97% think that virtual 3D teaching better prepares them for the practical dissection course which was one of our central goals in this project. This clearly helps us to use expensive dissection room infrastructure in a for the students most efficient way. 93% of the students answered that virtual anatomy increases their interest in the subject anatomy and finally 98% of the students think that 3D presentations help them to better achieve their learning goals. Hence all our research hypotheses and goals have been approved. We also asked if the scope of 3D content was adequate or shall be increased. 36% of the students were satisfied with the amount, 66% wanted to extend the number 3D lectures.

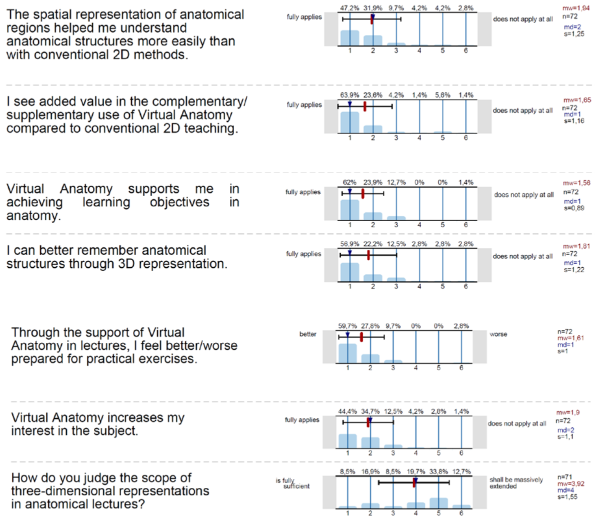

Fig. 6. Detailed evaluation results in connection with our research hypotheses

Results in connection with presence are given in **Fig. 7**. A majority of 94% of the students could fully concentrate on the 3D anatomical structures without being distracted by technology. 79% of the students felt immersed by the virtual anatomy tools and 67% of the students had the feeling to see the anatomical tissues directly in front of them even though sitting up to 40m away of them.

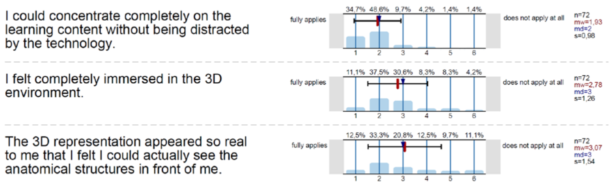

Fig. 7. Selected evaluation results from the presence section.

In the section usability we received the results as given in **Fig. 8**. According to these results 98% of the students were satisfied with the logistic process designed by us for glasses distribution and return. 93% stated that the quality of our new LED wall was excellent. 94% of the students could see the tissues spatially and stereoscopic. ~80% of the students were satisfied with the technical support we provided during the pilot trial and ~60% stated that there were no significant delays of the lectures due to technical failures.

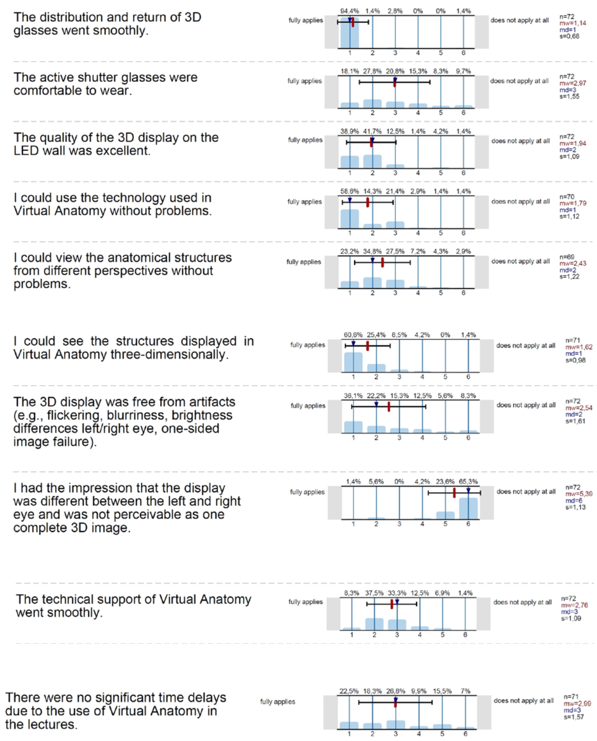

Fig. 8. Selected results from the section usability.

5.3 Measurements derived from evaluation results

From the two open questions we received a lot of useful feedback from the students in connection with improvements. After a thorough analysis of the comments we finally identified 6 measurements for improvement.

3D info sheet: provision of a technical information sheet and a short intro at the beginning to make students familiar with the basics of the technology and the logistics.

Improvement of illumination: the illumination of the tissues is essential for a good visualization and it turned out that existing lights in the lecture room are not sufficient. Additionally, their frequency interferes with the camara frequency which results in flickering. So, we decided to buy a dedicated mobile spotlight for the 3D camera and to fully darken the lecture room.

3D recording: in case lecturers become ill or a tissue is not available 3D recordings are helpful so students can still have the stereoscopic view. We decided to implement a local 3D recording possibility.

Localize defect glasses: students reported that several glasses were broken. We tested them all and sorted out the broken ones.

2D - 3D - 2D: some students reported that a mixture of 2D and 3D would be much more comfortable and much less strenuous than 45 min 3D. However, this is hard to achieve in a 45 min unit since lecturers would have to disinfect / remove and put on gloves when switching between dissection table and computer with 2D content.

Hybrid teaching: possibility to stream the 3D views so students can follow (in 2D) also from home. This is currently prohibited by the lecturers due to ethical reasons.

6 Summary and conclusions

The given virtual anatomy comprises three virtual teaching scenarios, two on site in presence, teacher driven and in stereoscopic 3D with the possibility to offer it for students also in 2D hybrid, one suited for presence and virtual asynchronous teaching (student driven teaching). All three teaching scenarios are capable to serve large student groups of 500+ students.

All three scenarios were actively integrated into the anatomy curriculum starting in October 2024, where we started a pilot trial amongst 500 medical undergraduate students on the lecture conduits and intestines. The pilot trial was accompanied by an evaluation, which resulted in excellent results encouraging us to continue and intensify our approach.

From the evaluation results it can be derived that all our research hypotheses have been approved. One of the most important results was, that ~97% of the students stated virtual 3D teaching better prepares them for the practical dissection course. Hence expensive dissection room infrastructure can be used in limited times slots from the students in the most effective way.

Next to many comments encouraging us to continue we could derive six measurements for improvement from the. student feedback including a 3D info sheet, improvement of illumination, 3D recording, alternate 2D/3D phases and provide a hybrid scenario.

7 Outlook

As an outlook we currently open the virtual anatomy to enable virtual 3D teaching technology also to other clinics and institutes such as neurosurgery, urology, ENT department and radiology clinics. For this purpose, we will technically provide a possibility to connect a standard laptop capable of running 3D software directly in the huge lecture room for displaying on our 3D LED wall. Additionally, we also plan a small scale mobile 3D solution for seminar rooms and small groups of students.

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