Active Implementation and Integration of Virtual Anatomy into undergraduate medical teaching

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Abstract. Anatomy education in medical undergraduate curricula traditionally depends on the provision of human tissues, which involve significant infrastructural and personnel resources. More importantly, a gap involves between traditional teaching approaches and contemporary technology. To address this challenge, virtual tools offer one promising approach by providing a realistic spatial learning experience, particularly fulfilling the needs of universities lacking the provision of post-mortem facilities for anatomy teaching. This given project explores three technical scenarios integrating virtual tools into anatomy teaching. Scenario #1 utilizes live-rendered three-dimensional magnetic resonance imaging (MRI) models for large student cohorts, Scenario #2 live 3D-broadcasting of anatomical dissections to a large audience. Scenario #3 focuses on the provision of digitizing anatomical models for online access. Visual use cases and organizational concepts were developed to streamline implementation and logistics. Initial feedback suggests acceptance and potential effectiveness in enhancing anatomy teaching. These findings highlight the value of integrating virtual tools into traditional anatomy education methods.

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

1 Introduction

Anatomy teaching in undergraduate medical education is commonly conducted using human tissues from body donors. This requires a complex technical infrastructure, and highly qualified involved in the numerous processes related to the provision of tissues. Mortuary facilities and dissection rooms remain costly to operate in spite of recent efforts involving Value Engineering, hence room capacities and time within the facilities are limited. To use dissection rooms in an efficient manner, virtual tools may provide a realistic spatial learning experience and help prepare students effectively for their dissection lessons [6]. Virtual tools may also help translating theoretical knowledge to other fields in medicine such as radiology or neurosurgery. On the other side, hands-on teaching in dissection rooms cannot be replaced by virtual tools at the current state of technology, and likely not in the next decade or two. Spatial, haptic and procedural steps involved in medical teaching cannot be replaced by virtual technology. Virtual tools offer new possibilities in anatomy teaching, due to virtual 3D presentations of MRI data which enables teaching anatomy on living humans.

In terms of technical implementation, three scenarios have been assessed, driven by suitable use cases for individual teaching processes, which may help enhance the classical approaches of teaching anatomy by taking advantage of virtual technology. Scenario #1 implements live-rendered three-dimensional (3D) models derived from MRI datasets obtained from living subjects by utilizing the Cinematic Rendering® technology, a novel technique for post-processing medical imaging data [14] combined with a commercial rendering software [15] and a 3D visualization technology installed in large scale lecture halls. Didactically Scenario #1 is designed for teaching larger cohorts of students, up to 500 in a simultaneous manner. The audience is intended to observe and study the content presented in 3D via active shutter glasses. The 3D content will be controlled by one lecturer using an Xbox controller based on live renderings from MRI models of humans, supported by software engineers to assist in running the system and preloading the datasets with the numerous anatomical structures reconstructed.

Scenario #2 is based on a 3D camera mounted on a crane and placed on a cart. The cart can be moved to the dissection room or other suitable teaching spaces for the live transmission of a dissection commented by the teacher to the local lecture room and our partner university. The resulting 3D visualizations in the lecture room will again be achieved by active shutter glasses worn by the students.

For scenario #3, 110 historical wax models, human bones and plastinates were scanned using contemporary 3D scanning technology. These 3D models were uploaded to a designated software which allows for making annotations by trained anatomists, and for the embedding of the models into the Moodle learning management software. Students may access and manipulate these objects with a standard web browser from any device connected to the Internet.

2 Research goals

Virtual approaches are likewise relevant for universities which may decide not to integrate full-scale anatomy faculties for budgetary or infrastructural reasons or due to the lack of expertise at times with growing demands for trained anatomists and at the same time a rapid decline in the number of anatomists available for tertiary training institutions. The time spent in the dissection facilities of mutual partner universities providing those facilities is limited and comes with additional costs related to traveling and housing for the students. This makes a proper preparation for hands on courses essential for a good learning experience and success.

The hypothesis and goal of this given project was that, as a result of using virtual tools accompanying teaching and student learning gain during theoretical, lessons will be enriched in terms of providing an immerse approach for delivering traditional anatomy teaching content in live 3D models offering students a better understanding on spatial positions of organs, muscles and bones within corpses. The value using 3D in anatomy teaching has already been substantiated in recent studies. In [1] anaglyph glasses were utilized, enabling the viewer to appreciate structures in 3D. As a result, the visualization of 3D anatomical structures increases the learning performance of students. In [2] the result suggests that the 3D group achieved at least similar or slightly better results than the comparison group using 2D documents. The students rated the 3D method as better in several areas and saw it as superior to the 2D presentation.

The here chosen methodology allows 3D representations of living human bodies, which provides even an add on to dissection rooms, e.g., by the visualization of veins.

As a main challenge of this project the active integration of the developed technical scenarios in the standard teaching process of our anatomy teachers at the university can be considered.

3 Related work

With the terminology "Virtual Anatomy" usually technologies like virtual and augmented reality are related. However, all these technologies still suffer from appropriate scaling. We have to teach student cohorts with up to 500 students, hence augmented reality was not a technical option for us. In our implemented scenarios we will use a special 3D rendering technique and a 3D transmission technique, both unique according to our market research. The 3D rendering technique is currently only used at our partner university [14] with whom we cooperate in this project and will further develop it to a networked scenario.

Virtual reality initiatives in connection with anatomy teaching in our country include the young Austrian startup company Augmentomy [7] which develops within an European Community supported research project an augmented reality (AR) solution for teaching anatomy. The startup company began in 2023 with the development of software for Qualcomm AR glasses. A typical use case for this application was a small-scale classroom setting offering interactive collaboration. For the scenario required with 480 students, this software cannot be used in an efficient way due to the need of expensive AR glasses and restrictions in interaction.

The research project nARvibrain [8], performed in a collaboration between Medical University of Graz and the University of Applied Sciences FH Joanneum in Austria, aims to detect brain tumors by combining of AR technology with radiology. The aim is 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, the hardware required would not be affordable for 480 students in parallel.

There also exist a number of medical simulation programs including HoloScenarios developed by the simulation company GigXR [13] in collaboration with the Cambridge University hospitals. The software provides a realistic simulation of the entire patient care journey, but there is no direct connection to anatomy and anatomy in education. Hence this software is more suitable in a later stage of the medical education, where students are already in their clinical years.

For scenario #3 we were assessed a number of platforms capable of distributing 3D objects, including Online 3D viewer [9], 3D Vault [10], CG Trader [11], Visibly Body [12] and Sketchfab [16]. 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 reasonable 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 Visual use cases and active integration into teaching

Starting from nine 7-dimensional use cases [5], research was focused on developing innovative visual methods and practical studies to assist lecturers effectively, thereby adapting their lessons to utilize the new virtual tools. To support the planning of the single lessons so-called visual use cases were defined based on the already existing use cases. Next to this, all preparation steps necessary to be completed before and following the lesson are given in detail.

4.1 The concept of visual use cases

A visual use case represents one of the main use cases and there one single specific lesson including its timely representation. A visual use case shows all the important elements of the lesson in tracks on a time scale on a single DIN A3 sheet. These tracks represent the necessary teaching content, resources and involved staff, the student actions and the necessary actions taken by the teacher (e.g., change between 3D and 2D representations). In **Fig. 1** all the necessary preparation and follow up steps are visualized.

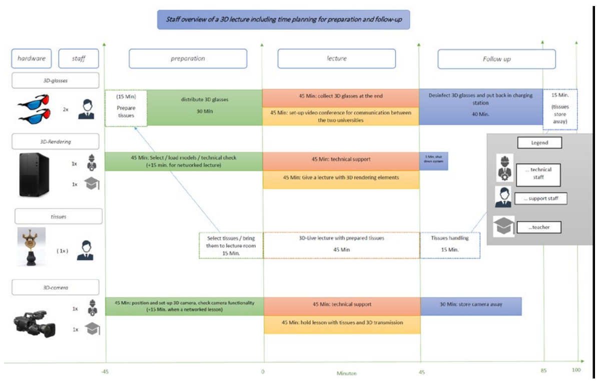

Fig. 1. Visual use case preparation steps

In this overview it can be clearly seen, that for a 45 min lecture at least 30 min preparation and 40 min follow up actions are needed. Furthermore, on the left side the needed resources in terms of staff and hardware are stated.

In **Fig. 2** a concrete visual use case for a networked 3D live transmission is displayed. The visual use case is built up on four tracks representing parallel actions over the lecture time. Tracks include the learning content, the video conference set-up between the two universities for teacher communication and synchronization and also to communicate questions from the students, the student actions, the necessary interactions at our university with the 3D camera and the AV (audio visual) media controller interface to set-up 2D/3D transmission and the display on the LED (light emitting diode) wall at our university. The last track represents the time scale and the display mode (2D or 3D).

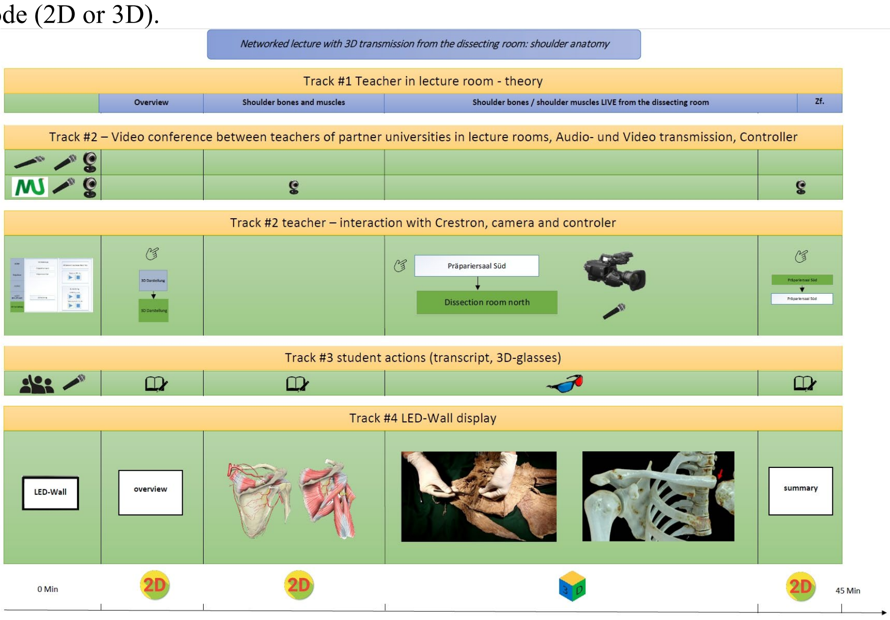

Fig. 2. Visual use case for a networked 3D live transmission

Fig. 3 demonstrates a visual use case of one of the most complex scenarios, in technical terms. The underlying use case describes a networked lesson between our university and our partner university, technically a very complex networked scenario, where the 3D parts are controlled by a teacher residing at our partner university, the 2D parts are given by a teacher of our university. In the different tracks the parallel actions of the use case are displayed visually: content, 2D AV conference for communication between the teachers at the different locations, interaction of teacher with AV media controler on our side and XBox controller for 3D content on remote side, actions of students and the display on our 3D LED wall.

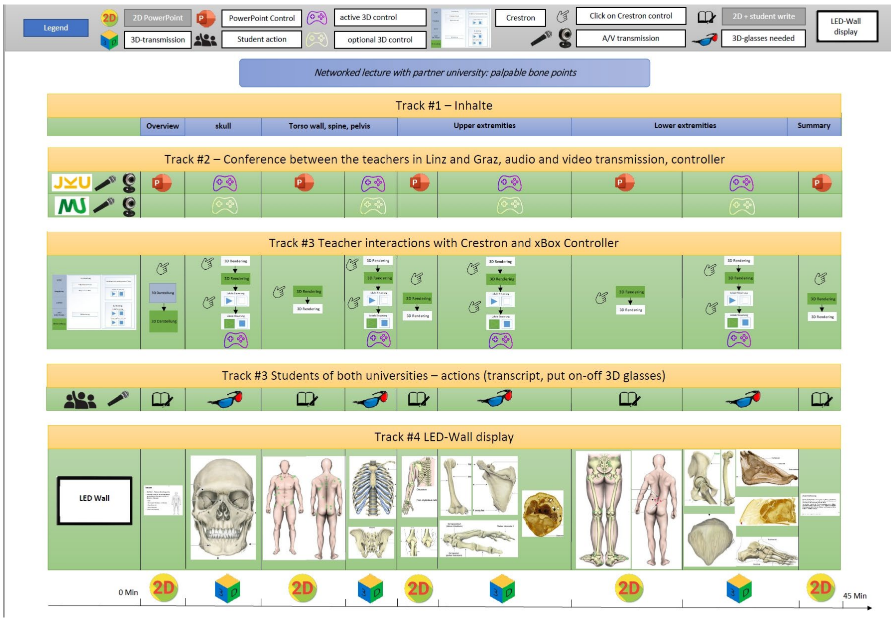

Fig. 3. Visual use case "networked lecture" with partner university on palpable bone points

In summary it can be stated, that visual use cases offer a comprehensive overview on the efforts to be taken in order to plan and implement specific lessons and are regarded as a very helpful instrument for teachers in order to properly prepare their lesson and content.

4.2 Organizational concept of practical 3D shutter glass handling with large student groups

Next to this an organizational concept was developed for the pre- and postprocessing steps to establish the 3D scenarios #1 and #2 in the large lecture room of our anatomy institute. This includes a detailed time schedule and estimation especially in connection with logistics of the 3D glasses, i.e., the hand over to students, recollection, disinfection and recharging procedure for groups of 500 students.

In **Fig. 4** the 3D glasses logistics are given in three phases: pre-processing, lecture, post-processing. In the pre-processing phase the 3D glasses are collected from the charging racks and distributed in baskets. Those baskets are located near the entries of the lecture room and each student entering the lecture room will be handed over one pair of glasses by administrative staff. During the lecture phase administrative staff will be in the lecture room in order to replace defective devices reported by students. In the post-processing phase the 3D glasses are collected again in the baskets next to the exits. After collection they are transported to the prearrangement lecture room, where a bely conveyor-controlled disinfection device is located. After disinfection 3D glasses are either put back in the baskets, in case another 3D lection takes place on the same day, or put back into the charging racks.

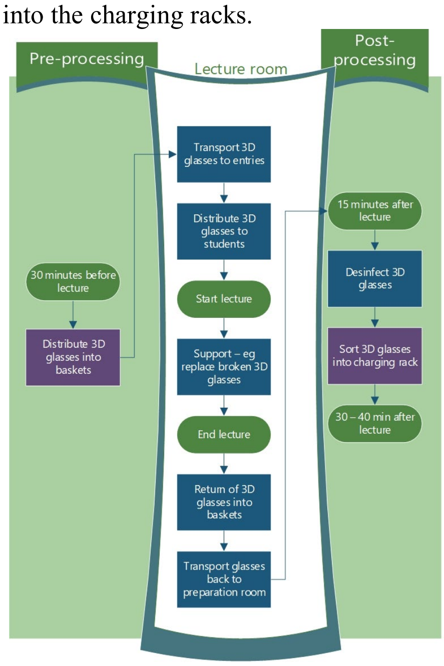

Fig. 4. 3D glasses logistics

In **Fig. 5** a time overview on the 3D glasses logistics is given. All in all we need 30 minutes preparation time before a lecture and up to 40 min post processing time after a lecture. 30 min post processing are needed if there is another 3D lecture on the same day, 40 minutes are needed after the last 3D lecture for disinfection and putting back the 3D glasses into the charging rack. With respect to personnel resources two admin persons are needed for the distribution and collection of 3D glasses, and during the lecture for support.

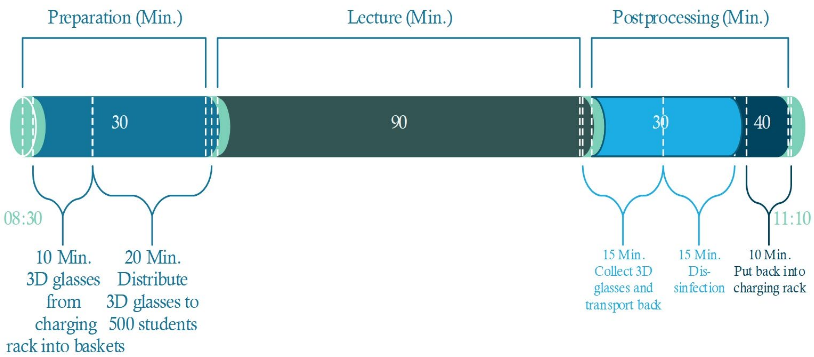

Fig. 5. 3D glasses logistics timely overview

5 Technical implementation

In the following sections the technical implementation of the three scenarios is given in more detail.

5.1 Scenario #1 - A lecturer driven 3D live visualization of (living) human tissues based on MRI scans

Scenario #1 will be implemented by 3D cinematic rendering, a novel technology for the post-processing of medical imaging data [14] with a commercial rendering software [15] which will be installed on a standard high-end server with a state-of-the-art graphic card (NVIDIA RTX 5000 "Ada") in order to render the two images (left/right eye). Furthermore, a 3D display technology will be installed in our huge lecture room. Didactically, the scenario is designed for the teaching of a large student cohort of 500 students, offered the content in a classroom setting in 3D via active shutter glasses. The visualized 3D content will be presented by the lecturer with a XBox controller based on live renderings from MRI models of humans. This enables case-based teaching on living persons, e.g., by visualizing a vertebral fracture of a person fallen from a horse, its actual effects on the person and the proper therapy. Additionally, a 2D version will be streamed [4] so students may follow the lesson from home, which classifies this scenario as hybrid [3].

Based on a list of technical criteria we did a market analysis on possible 3D visualization technologies suitable for a huge lecture room with 500 students. As a result, a LED wall solution with active shutter glasses was chosen.

LED walls, while not a new technology, are currently cutting-edge when combined with 4K 3D visualization. Few vendors offer this advanced technology. The crucial element is the proper controller, which can drive individual displays in parallel at 4K resolution and 120 Hz (60 Hz for each eye). Our research indicates that LED technology is the future for lecture room visualization. In smaller lecture rooms, LED panels are already state-of-the-art. For our specific installation, LED walls offer the following advantages over projectors: they provide superior brightness and contrast, are less complicated to install, and have a longer lifespan. Although LED walls are typically used with active shutter glasses, there’s a possibility of using passive shutter glasses with a special foil attachment.

Actually, active shutter glasses were not our preferred solution due to the fact, that they are more expensive than passive shutter glasses, they require a battery which must be regularly charged and the logistics are more complicated, as it was stated in the chapter before. Due to limited vendors, we’ve chosen active shutter glasses for our needs. For the charging process we decided to buy inductive loading cabinets which offer space for simultaneously loading up to 192 glasses. Since a cable connection is not necessary, the manual efforts for the charging process are significantly reduced.

The lecturer controls the software using a standard Xbox controller. With the controller sticks, they can navigate through the model and choose which layers (muscles, bones, veins) to display. Real-time 3D images are generated based on the lecturer’s movements and sent to the LED wall controller for display. Students experience the

3D effect using active shutter glasses. Examples from the Ars Electronica Center in Linz demonstrate how this system looks; it has been in use for teaching anatomy by our partner university. A first 3D LED wall test was performed in June 2023 at NEC in Schwanstetten (Germany), see **Fig. 6**. There we successfully demonstrated the cinematic rendering on a NEC LED wall, which had a quarter of the size we have planned in our lecture room. The test results were extremely positive, especially the contrast of the LED wall was much better than anyone of us had expected.

Fig. 6. First LED wall test with Cinematic Rendering at NEC in Schwanstetten (Germany)

5.2 Scenario #2 - 3D live video transmission from the dissection rooms

The didactical purpose of this scenario is to provide our students in the large lecture room and those from our partner university, which lacks a dissection room, with a realistic dissection experience on a human corpse. This complements the virtual anatomy lectures for students at our partner university. The scenario involves a 3D camera mounted on a crane and placed on a cart. The goal is to conduct a live 3D transmission of a dissection, narrated by a lecturer, to both our large lecture room and our partner university. 3D visualization in the lecture room will be achieved using active shutter glasses. Technically, the scenario faced two challenges: selecting an appropriate 3D camera and achieving long-distance transmission over the Internet.

With regards to the 3D camera there are two possible technical solutions: the mirror rig technology and the side-by-side technology. Mirror rig technology allows filming in the macro range, providing high detail for small objects. It is commonly used in medical applications, such as neurosurgery. However, it is expensive due to individually manufactured rigs. The less expensive side-by-side rig, consisting of two standard cameras on a rack next to each other is not able to film in the macro range. We tested both technologies in August 2023 in our dissection rooms and we finally decided to choose the mirror rig solution, due to much more flexibility in distance to the objects and providing the possibility for close ups of important regions to be displayed, see **Fig. 7**.

The second challenge was achieving real-time, fully synchronous long-distance transmission of the two 4K streams (left and right eye) from the 3D camera to our partner university over the Internet. Key issues include minimizing the delay (targeting around 200 ms) and ensuring synchronicity between the left and right eye streams. We opted for frame sequential transmission, maintaining 100% synchronicity while halving the frequency from 60 Hz to 30 Hz. This choice allows us to achieve maximum resolution for our display while still meeting acceptable quality standards.

Fig. 7. 3D camera tests at university dissection rooms

5.3 Scenario #3 – Visualization of 3D scans of anatomy objects within a standard web browser

For scenario #3 we have set-up the full workflow including scanning, annotating and presentation to the students. Next to a 3D handheld scanner [17] working with blue LEDs we have introduced also a 3D scan box [18] which works with photogrammetry, enabling scanning of objects up to the size of a human skull in a much better quality and speed due to fixed mounted cameras inside the box.
In the workflow of the scanning process, we faced many challenges, due to the fact that most of the scanners are used in the mechanical, automotive or other hardware industries where most objects are easy to scan by the reason of a consistent surface.
However, scanning anatomical preparations, we dealt with surfaces neither as smooth nor structured, many surfaces in and on the specimens being profound and glossy. To deal with these technical challenges a lot of practical knowledge and technical aids like extra reference cubes, special camera settings or post processing have been used. Also, the topic of the subject size occupied us because some specimen parts to scan where very small or thin (arteries, veins).
In the next step of the workflow, we have selected a proper cloud-based software platform for annotation.
Sketchfab we choose because of a big upload capacity, editing settings and properties, making annotations possible, having an embed code and the most important point having the best private settings started. Currently, we have 112 models in all categories (wax models, bones, plastinates, formalin fixated specimens) on the platform and are in the state of taking settings, naming and annotating the models, some examples are visualized in **Fig. 8**.

Fig. 8. 3D scans of an embalmed human brain, a wax model of a fetus and a plastinated lung

For the last part in the workflow, making the models visible online for the students, we currently are in the process of integrating the models into Moodle and in the teaching process.

6 Summary, conclusions and recommendations

Based on first feedback from the anatomy staff, the given approach of visual use cases, visualizing thoroughly - on the time scale of one lesson - all necessary efforts, teaching content, needed supporting personnel and resources on one page appear to be well accepted. Hence it will actively assist anatomists in amending the current way of anatomy teaching by the use of innovative 3D virtual tools. Together with the nine multidimensional use cases defined with the teachers of the institute of Anatomy, it helps to prevent the worst-case scenario, which would be the teachers not using the expensive and pre-installed technical infrastructure.

Scenario #1 enables case-based anatomy teaching based on clinical imaging datasets derived from living subjects. The chosen technical solution, a NEC LED Wall, offers in comparison to a projection several advantages including: much better contrast and viewing angle, better colors, higher life time and less cooling noise. Additionally, a 2D version is offered to be streamed so students may follow the lesson from home.

Scenario #2 gives students a realistic spatial 3D representation of the dissection procedures, in contrast to traditional teaching methods with 2D images. In comparison to photos and books, the 3D representation offers a realistic view and improves the understanding and learning of the human anatomy, which is in its nature three dimensional. One of the main technical challenges in this scenario is the real-time and fully synchronous long-distance transmission of the two streams of the 3D camera (left and right eye) over the Internet to our partner university.

Scenario #3 offers a low barrier possibility for students to access and manipulate anatomy objects with a standard web browser from any place, without having the need of special technical equipment. Only an Internet connection is required.

References

1. TV Peker, ÖA Dizakar, D Dayanır: "Developing an Anatomy Lecture Model for Medical Students Using 3D Anaglyph Imaging Method", Gazi Medical Journal 4(33): ss.356-359, https://medicaljournal.gazi.edu.tr/index.php/GMJ/article/view/3140/2606, 2022.
2. R. Kockroa, Ch. Amaxopouloub, T. Killeena, W. Wagner, R. Reischa, E. Schwandt, A. Gutenberg, A. Giesec, E. Stofft, A. Stadiec: "Stereoscopic neuroanatomy lectures using a three-dimensional virtual reality environment". In Annals of Anatomy 201 (2015) 91–98, https://pubmed.ncbi.nlm.nih.gov/26245861/, 940-9602, Elsevier.
3. I. Fallmann et al.: „Quantifizierung von virtueller Lehre an österreichischen Hochschulen", Whitepaper CC BY, Forum neue Medien Austria, <URL: https://www.fnma.at/medien/fnma-publikationen> (Jun. 2021) also available as result of the Austrian University Conference „Empfehlungen der Hochschulkonferenz – Digitales Lehren, Lernen und Prüfen am Hochschulen" (Dez. 2021).

4. H. Rehatschek: "Outline of Possible Synchronous Solutions and Experiences in Order to Supply Large Groups of Students with Learning Content in Classroom and Mixed Classroom/Distance Scenarios". In proc. of the 24th ICL2021, Volume 1, LNNS 389, ISBN 978-3-030-93904-5, published by Springer on 1 Jan 2022, https://doi.org/10.1007/978-3-030-93904-5_52, pp. 523–534, 22 - 24 Sep. 2021, Dresden, Germany.
5. H. Rehatschek, N. Hammer, T. Schrangl: "A Use Cases Driven Design of a Virtual Anatomy". In Proc. of the 26th ICL2023: "Towards a Hybrid, Flexible and Socially Engaged Higher Education", Lecture Notes in Network and Systems, Volume 2, eBook ISBN978-3-031-52667-1, Softcover ISBN978-3-031-52666-4, https://doi.org/10.1007/978-3-031-52667-1, pp. 11 - 22, 26–29 Sep. 2023, Hotel NH Ventas, Madrid, Spain.
6. JF. Niedermair, V. Antipova, S. Manhal, M. Siwetz, M. Wimmer-Röll, N. Hammer N, F. Fellner: „On the added benefit of virtual anatomy for dissection-based skills“. FA.Anat Sci Educ. 2023 May-Jun;16(3):439-451. doi: 10.1002/ase.2234. Epub 2022 Dec 15.PMID: 36453060
7. Augmentomy, application of augmented reality in medical education. <April 2024 / URL: https://augmentomy.eu/>
8. nARvibrain, merging or neuro-imaging data. <April 2024 / URL: https://www.medunigraz.at/news/detail/narvibrain-erleichtert-hirntumordiagnostik>
9. Online 3D viewer, website which can open several 3D file formats and visualize them in a browser. <April 2023 / URL: https://3dviewer.net/>
10. 3D Vault, platform for uploading and sharing 3D objects. <April 2024 / URL: https://www.augment.com/blocks/3d-vault/>.
11. CG Trader, inventory for 3D objects and 3D objects exchange. <April 2024 / URL: https://www.cgtrader.com>
12. Visibly Body, interactive A&P and biology products for the web and mobile devices. <April 2024 / URL: https://www.visiblebody.com>
13. GigXR, holographic healthcare training. <April 2024 / URL: https://www.gigxr.com/>
14. F. A. Fellner: “A novel technique for post-processing medical imaging data”. In Journal Biomedical Science and Engineering Vol. 9 No. 3, ISSN Print: 1937-6871, ISSN Online: 1937-688X, http://dx.doi.org/10.4236/jbise.2016.93013, pp.170-175, 2016.
15. Syngo.via, Cinematic Rendering Software. . <April 2024 / URL: https://www.siemens-healthineers.com/at/digital-health-solutions/cinematic-rendering>
16. Sketchfab, a platform for distributing3D and AR models. <April 2024 / URL: https://sketchfab.com/>
17. Artec Space Spider, professional industrial 3D scanner. <May 2024 / URL: https://www.artec3d.com/de/portable-3d-scanners/artec-spider>
18. ACMIT, Austrian Center for Medical Innovation and Technology. <April 2023 / URL: https://acmit.at/>