3D Organon VR Anatomy

Research Papers

RESOURCE REVIEW

DOI: dx.doi.org/10.5195/jmla.2022.1341

3D Organon VR Anatomy. Medis Media Pty Ltd, 2/23 Illawong Str., Surfers Paradise, Gold Coast, Queensland 4217, Australia; https://www.3dorganon.com/; prosupport@3dorganon.com; +61.4.5190.5904; individual and institutional subscriptions, contact for pricing.

INTRODUCTION AND BACKGROUND

Before launching into the review of 3D Organon VR Anatomy, I feel it would be helpful to provide some background information on virtual reality (VR), the hardware involved, and my personal experience using VR in the arena of medical libraries and medical education. What exactly is virtual reality? I particularly like this definition from the Virtual Reality Society, which describes VR as

> a three-dimensional generated environment which can be explored and interacted by a person. That person becomes a part of that virtual world or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions [1].

The key factor in this definition is the idea of immersion, which separates virtual reality from other forms of "reality" such as augmented or mixed. These add virtual elements to your physical reality but do not immerse you fully in a virtual realm. The virtual reality headset, which in technology parlance is often referred to as a head-mounted display (HMD), completely dominates your field of vision and, with attached headphones, your sense of hearing, thus providing a truly immersive experience. It is that immersive aspect that has made VR a powerful tool in medicine, for example treating combat veterans with PTSD [2] or helping burn patients with pain management during treatment [3].

Oculus by Facebook [4] and Vive by HTC [5] continue to be the major players in the VR landscape since they first introduced headsets to the market circa 2016; however, there is now a whole line of headsets from other companies that are compatible with Windows 10. Oculus has moved away from PC-powered VR in recent years to focus on their stand-alone VR headset, the Quest. PC-powered VR is still the higher-end experience based on utilizing a high-level graphics card and the processing power of a gaming computer; however, in terms of price range for a virtual reality station, it could fall between $2,500 and $5,000, depending on the machine purchased and peripherals. Pricing for the Quest 2 starts at $299, and it is a quality VR experience. I have personal experience using the HTC Vive and Vive Pro, the Oculus Rift, and the Oculus Quest and Quest 2.

My experience with virtual reality dates to the early 1990s when the company Virtuality [6] set up a demo of their game *Dactyl Nightmare* at the student union while I was a student at Miami University in Ohio. At that point in time, the processing power was not sufficient to make VR a commercially viable product. VR in 64-bit graphics just does not compare to the VR technology of today. In March 2017, I was able to attend South by Southwest, and a major theme of the conference was virtual reality's use and impact in medicine, which reignited my passion for VR in connection with my role in medical libraries. In October 2017, the Ruth Lilly Medical Library technology team was invited by NNLM to speak at the Midwest Chapter and MHSLA conference [7]. My part of the presentation focused on VR in medical practice. An article published in 2018 details the RLML tech team's early days with VR and 3D printing [8]. The *JMLA* virtual project published in 2019 details my role in the creation of the Nexus Virtual Reality Lab at the Ruth Lilly Medical Library [9]. Since mid-2017, I have introduced hundreds of medical students, faculty, and staff to VR for the first time. In terms of exploring the landscape continuously for useful VR programs, 3D Organon VR Anatomy has always been the go-to showcase program for me to demonstrate how this technology could be utilized in medical education.

3D ORGANON VR ANATOMY

3D Organon VR Anatomy was featured by Mark Zuckerberg in his keynote address at the Oculus Connect 3 conference in 2016 and has won numerous awards [10]. The company Medis Media, which produces 3D Organon, was formed by Dr. Athanasios Raikas and Dr. Panaigoti Kordali, anatomy instructors at Bond University in Australia [11]. Their knowledge of anatomy, along with a team of highly skilled programmers, forms the backbone of the program as reflected by its quality. According to a brochure provided by the company, 3D Organon is broken into fifteen human body systems with more than 10,000 realistic anatomical structures, over 550 action modules of muscles and organs, cadaveric images, and microscopic anatomy models. The true power of the program lies in being able to virtually inspect each anatomical structure, turning it and manipulating it to see it from all angles, and being able to see how the structures connect within each system in this truly immersive environment. In terms of my experience with medical students, the 3D aspect really helps students grasp what the structure is, where it fits, and its role within the system. For each structure, there is a detailed description. There is the ability to fade out structures so a student can really focus on its individual placement within the system. The program is also available in fifteen languages and includes recording options for instructors to share video with students from the program as well as drawing modes to help highlight structures. The interface and

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action with the VR controllers is highly intuitive, and it does not take long for a user to get comfortable with the program. The installation process for PC-powered VR is simple; however, the Oculus Quest installation process is more difficult because it is not available in the Oculus store. The company does provide detailed installation instructions, and they offer a great deal of content on their YouTube channel that certainly helps to visualize what the program can do [12].

The program offers different pricing tiers based on the platform and added features. There are prices listed on their website for individual use licenses, but for institution pricing the company must be contacted for a tailored quote [13]. They follow a twelve-month subscription model. The least expensive option is for stand-alone VR like the Oculus Quest 2. There are a standard and a premium version for PC-powered VR. The premium version includes additional content like USMLE testing modules. Depending on the VR headset you are using with the PC-powered option, there are additional augmented reality features where you can overlap the VR image over an actual person. The company has expanded its offerings into different formats, but the true strength of the program is that it is one of a kind in the VR realm.

COMPARISONS

It is difficult to conceive of direct comparisons for 3D Organon in the VR space. Complete Anatomy by 3D4Medical is a popular anatomy program utilized by students, but it is not available for VR. Being able to manipulate structures and view them from any angle is certainly a strong selling point in the immersive environment of 3D Organon [14]. It does appear that 3D4Medical is dipping their toes into mixed reality with their program Holohuman, and it works with the Microsoft Hololens, but I have no direct experience with it [15]. Primal Picture's Anatomy TV has a VR component now, but I have never found their 3D functionality very user friendly [16]. The controls and functionality of 3D Organon are natural and user friendly in comparison, with the program having been designed specifically for VR. You by ShareCare is an impressive VR program in terms of its visualizations and is certainly a program I recommend based on it being inexpensive; however, it lacks the breadth of information available in 3D Organon and its user interface is quite complex [17]. In terms of VR programs that are applicable to medical education, 3D Organon is the best I have encountered.

USE CASES

I have been in contact with the company, and they provided a listing of US libraries that have used 3D Organon. These include Western Carolina University Hunter Library, Eastern Carolina University William E. Laupus Health Sciences Library, California State University Fullerton, and Temple University Ginsburg Health Sciences Library. I am aware of local institutional use in the Indianapolis area by the Ruth Lilly Medical Library and Marian University. The company lists multiple international use cases on their website. There is still a relatively inexpensive version of the program available on the Steam platform and the Oculus store. The company was clear that this version is intended for personal use and having it installed on machines accessible to multiple users would be a violation of the license agreement. This was the version that I was using to demonstrate the program. It serves as an example that as these companies grow, they are learning to monetize their products more effectively. In my experience, most VR programs are licensed for single use without consideration for multi-user situations like a library. The workaround had been to buy one license for each machine the program was installed on. This is an evolving issue with VR applications.

The best use case I am personally aware of for the implementation of 3D Organon in medical education was conducted by Debra Patterson, assistant professor of clinical and imaging sciences at the Indiana University School of Medicine [18]. During the fall semester of 2019 and into the spring semester of 2020, Patterson incorporated 3D Organon labs into her undergraduate classes for medical imaging. The first lab was structured to familiarize the students with the VR equipment and the program itself. The second had them use the program to answer specific questions about the external jugular vein. Based on specific student feedback such as "I would like if each week we had a different anatomy section we could explore and make our own anatomy assignment in a way," Patterson allowed more freedom in the third assignment for the students to choose anatomy in the program to describe, and the student response was highly positive: "I enjoy being able to choose anatomy I am interested in and describing how it is important to MRI." However, like so many things in 2020, her plans for the remainder of that academic year were disrupted by COVID-19 as classes were converted to virtual. Patterson has expressed excitement about building on her previous attempt and incorporating 3D Organon into future classes based on the positive student reaction.

CONCLUSION

We are currently seeking grant funding to establish a technology lab at the IU Health Medical Library, which would include VR stations and Oculus Quest 2s for department checkout. 3D Organon VR Anatomy is certainly a program that would be incorporated in this plan if funding is secured. The program is a true showcase of what VR can do in the medical field and a great software to demo when trying to get students, staff, and faculty excited about virtual reality.

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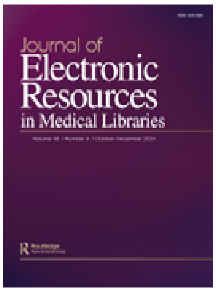
This journal is published by the University Library System of the University of Pittsburgh as part of its D-Scribe Digital Publishing Program and is cosponsored by the University of Pittsburgh Press.

ISSN 1558-9439 (Online)



Journal of Electronic Resources in Medical Libraries

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/werm20

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To cite this article: Emily C. Weyant & Nakia J. Woodward (2021) 3D Organon VR Anatomy: A Virtual Anatomy Medical Education Tool, Journal of Electronic Resources in Medical Libraries, 18:4, 198-203, DOI: 10.1080/15424065.2021.2000911

To link to this article: https://doi.org/10.1080/15424065.2021.2000911

Published online: 24 Nov 2021.

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JOURNAL OF ELECTRONIC RESOURCES IN MEDICAL LIBRARIES
2021, VOL. 18, NO. 4, 198–203
https://doi.org/10.1080/15424065.2021.2000911

INFORMATION RX
David Petersen, Column Editor

3D Organon VR Anatomy: A Virtual Anatomy Medical Education Tool

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ABSTRACT
3D Organon VR Anatomy is a virtual reality program that allows individuals to interact with anatomy in a 3D environment. This column provides a brief overview of the product and its potential uses within a medical library.

KEYWORDS
Anatomy; medical education; software; study tools; virtual reality

Introduction

More universities and libraries are incorporating virtual reality (VR) technologies into their educational toolboxes (Lessick & Kraft, 2017; Napa et al., 2019). It can be difficult to keep up with the rapid advances and changes to the wide variety of VR headsets currently available. That said, it may be helpful to first approach VR technology from the angle of software needed or desired, before delving into the plethora of hardware available. This column will discuss 3D Organon VR Anatomy by Medis Media Pty Ltd, one example of VR software currently available for anatomy related instruction (3D Organon VR Anatomy, 2021). 3D Organon VR Anatomy allows students to explore and interact with anatomy in ways not possible through books or online programs. This software allows students to assemble and disassemble the body, viewing anatomy at different angles and at different levels of detail. Interactivity could help students learn as they work directly with anatomy, viewing bodily actions and manifestations of illnesses in real time while taking assessment quizzes to test their knowledge. What follows is a discussion of different informational and interactive facets of 3D Organon VR Anatomy from a medical librarian perspective.

Informational and visual content

3D Organon VR Anatomy is an anatomy software program that contains a wide variety of information on the human body displayed in several visual

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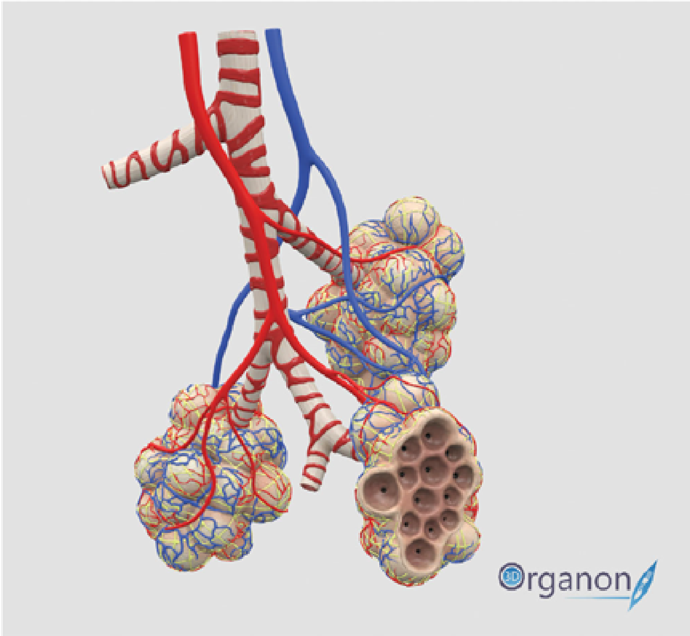

Figure 1. Detailed image example from 3D Organon VR Anatomy. ©[3D Organon VR Anatomy, Medis Media Pty Ltd]. Reproduced by permission of Krystyna Siposova 3D Organon VR Anatomy.

formats and available in multiple languages. This program showcases the body through 15 different bodily systems. These systems include the following: skeletal, connective tissue, muscular, arterial, venous, lymphatic, nervous, heart, respiratory, digestive, endocrine, urinary, reproductive, sensory, and integumentary (skin). 3D Organon VR Anatomy allows users to view different components of each of these systems, to pull them apart and reassemble them, and to turn them around to examine them from different angles. Some systems even allow for bodily actions, showing the way particular skeletal and muscular systems look while performing a specific action. This may be useful not only for medicine audiences, but also those studying physical or occupational therapies (Figure 1).

In addition to virtual depictions of these systems, 3D Organon VR Anatomy also provides x-ray and cadaver imaging. X-ray imaging provided by 3D Organon VR Anatomy behaves in the way one expects it to, allowing users to view different parts of the body as they would through an x-ray. This allows students not only to simulate the experience of reading an x-ray, but also to see different parts of the body transparently, thus assisting in their understanding of system placements and interactions (Figure 2).

Like x-ray images, cadaver images may help students more clearly understand the look and function of a system. Systems within the program are depicted as 3D drawings or images by default. These images are useful as they are depicted plainly and clearly in a 3D environment. Coupling these virtual images with cadaver images allows students to see the organ clearly

Figure 2. Example of 3D VR Organon Anatomy software in use. ©[3D Organon VR Anatomy, Medis Media Pty Ltd]. Reproduced by permission of Krystyna Siposova of 3D Organon VR Anatomy.

drawn, as well as realistically represented within a body. There is currently a cadaver shortage which the recent covid-19 pandemic has negatively impacted further (Rajasekhar & Dinesh Kumar, 2021). As such, it may be useful for libraries and medical schools to begin exploring other ways to work with cadavers considering this shortage. Some virtual reality programs, such as 3D Organon VR Anatomy and others like it, may assist with solving this problem.

There are several other ways that one may view and interact with bodily systems through 3D Organon VR Anatomy. These include grouping systems by bodily region, viewing them on a microscopic level, mapping them by bone structure, or examining the body topographically. In effect, 3D Organon VR Anatomy seeks to provide an anatomy textbook level of information on an immersive level. The ways in which one chooses to view the anatomy are up to the user.

Interactive features

In addition to interacting with anatomy on a visual level, 3D Organon VR Anatomy also allows users to pass knowledge to others or test their own understanding. Educators may screen-record themselves using 3D Organon VR Anatomy as part of their lectures. This allows them to focus on different bodily systems to a great level of detail and to take them apart and display them in whichever ways they need to effectively communicate a topic. Students may then work with the same software that their professor utilized to reinforce the lessons from the lecture (Figure 3).

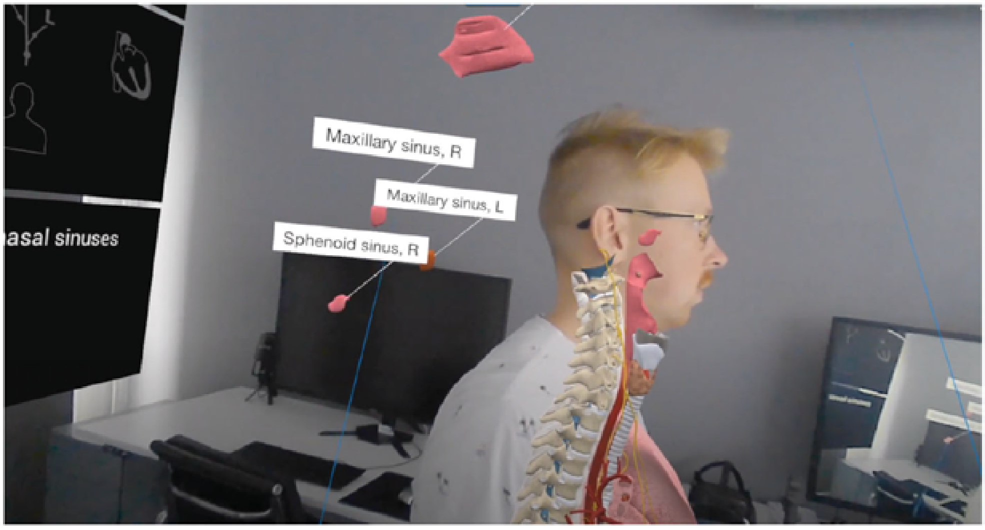

Figure 3. Example of 3D Organon VR Anatomy in use. © [3D Organon VR Anatomy, Medis Media Pty Ltd]. Reproduced by permission of Krystyna Siposova of 3D Organon VR Anatomy.

Some other ways for students to test themselves with 3D Organon VR Anatomy include assembling systems, painting images, examining clinical correlations, or taking notes and assessment quizzes. Students may start with disperse parts of a system and reassemble it from the ground up. 3D painting allows users to use their VR controllers as paintbrushes to emphasize specific parts of anatomy. This is particularly useful when explaining a system to a peer or student, and may assist with note taking or non-3D presentations. Clinical correlations display different pathologies and their interactions with anatomy, providing students with a visual representation of different conditions in real time. Note taking and assessment quizzes are somewhat self-explanatory, but it may help to know that students or educators can take personalized notes within 3D Organon VR Anatomy. Additionally, various quizzes are available within the program to test user knowledge of different systems and conditions relating to them.

Finally, students may interact with anatomy in 3D Organon VR Anatomy by overlaying effects such as tumors, bone spurs, and pain on different bodily regions. Tumor and bone spur effects allow students to explore the ways in which some medical conditions may progress in the body and what they look like at differing stages. Pain points are predominantly used by presenters or faculty to draw student attention to specific areas of common pain that may need to be addressed.

Limitations

As much as 3D Organon VR Anatomy may be useful to a variety of institutions, there are some barriers for libraries to implement the program.

Some of these barriers include limited library budget and space, which are not always negotiable. Concerns that may be more easily addressed include the learning curve to adapting to a working with VR, as well as addressing safety concerns for students wearing headsets within the library.

When considering purchasing a program like 3D Organon VR Anatomy, one must know that it requires not only an investment in the product license/subscription, but also in the hardware necessary to implement the software. VR software requires several hardware pieces including a VR headset, remotes, tripod stands, and a computer robust enough to run an interactive imaging program like 3D Organon VR Anatomy. Additionally, relevant cords, storage materials, and cleaning materials for the headset are also potential costs. Some organizations may wish to attach a television to the VR computer to facilitate students working in groups to view what the VR headset wearer is seeing. This is an additional fee to consider.

In addition to physical item costs, there is also the consideration that libraries must employ someone who can manage any updates and maintenance that the VR system may require. There is a learning curve for using VR equipment that varies across individuals. Therefore, some students and faculty may require more or less instruction when using the resource, meaning that it is likely that a library staff member will have to dedicate time to training on the equipment if it is to be used widely.

This all must take place in a space that can accommodate the VR equipment, as well as providing enough space for students to interact virtually within the program. As VR users will have their eyes covered, this may mean having a specific room for the VR system, or at least dividers so that the VR user may have a sense of safety and privacy while in the virtual environment. This means not only that the VR user may wish to have privacy from other library users, but that the flooring and other aspects of a VR room should be free of potential tripping hazards and other points of potential injury. Unfortunately, space is at a premium in many libraries and a dedicated VR room may not be a possibility for all.

Conclusion

3D Organon VR Anatomy is a useful interactive program for learning anatomy, provided that it is a good fit for your library, students, and faculty. It may be beneficial for librarians to learn about VR tools and databases before trying to implement them in their libraries. Although all libraries may not have the budget or space to implement such tools today, they could become influential in aiding students learning in the future.

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Interventional Pain Medicine 2 (2023) 100180

Contents lists available at ScienceDirect

Interventional Pain Medicine

journal homepage: www.journals.elsevier.com/interventional-pain-medicine

Virtual reality training and modeling to aid in pre-procedural practice for thoracic nerve root block in the setting of a schwannoma

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ARTICLE INFO

Keywords:
Extended reality
Virtual reality
Medical simulation
Transforaminal injections
Pre-procedural planning
Medical Education

ABSTRACT

Virtual reality (VR) is a tool to aid with pre-procedural modeling and practicing for complex procedures with anatomic variation. Here we demonstrate a case of a 64-year-old woman with neuroforaminal compression from a schwannoma that was modeled in VR in order to facilitate pre-procedural training prior to a transforaminal epidural steroid injection. The modeling session allowed for determination of the optimal fluoroscopic angulation to avoid any contact with the mass or nerve root during the procedure. This case study demonstrates a way to incorporate VR in pre-procedural planning and practicing for both learners and experienced interventionalists.

1. Introduction

Virtual reality (VR) has been increasingly used in recent years to simulate real-world environments in the medical field. It has found notable utility in procedural specialties, facilitating skill development while avoiding undue patient harm [1–3]. Surgical training programs, in particular, have taken advantage of VR simulation for improving visual spatial ability [1] and laparoscopic surgery skills [2]. Multiple studies have demonstrated improvement in resident operative room performance following training with standardized VR simulation [1–3]. VR simulation has also rapidly emerged in anesthesiology and pain management training, such as in administration of spinal anesthetics [4] and peripheral nerve blocks [5], as well as facet joint blocks [6,7] and spinal cord stimulator lead placement [8], with similarly encouraging results. A particularly promising application of VR training in pain management lies in interventional planning for individualized cases, such as in patients with anatomical variation or deformity. Here, we discuss the case of a patient that underwent a thoracic nerve root block with pre-procedural planning facilitated by VR simulation.

2. Case report

A 64-year-old female presented with four months of ongoing right-sided thoracic pain. She was found on MRI to have a right-sided mass in the T11/12 foramen causing moderate to severe stenosis and compression of the exiting nerve root (Fig. 1). This was deemed inoperable in her home country, and she subsequently sought a second opinion from a United States-based spine surgeon who then referred her for a nerve block to confirm suspected diagnosis of schwannoma in the right T11/12 foramen prior to surgical planning. The patient endorsed a neuropathic upper back pain radiating anteriorly to the abdomen, consistent with the T11 distribution, and had trialed and failed conservative measures like neuropathic medications and physical therapy. The patient provided informed consent to both interventional therapy and having her case published for research purposes.

A transforaminal epidural steroid injection (TFESI) was planned with the goal of approximating the location of the schwannoma inferior to the T11 pedicle at around the 6 o'clock position. Interventional planning was conducted using *3D Organon VR Anatomy (Medis Media)* on an Oculus Quest 2 VR headset by simulating the location of the mass on a virtual spine and determining an optimal approach. Replication of the lesion was performed by manually sizing the tumor dimensions on MRI and then utilizing Tumor Modeling features in the software, which allows for 3D illustration of a mass with the ability to modify its location and dimensions. The model was then compared to the MRI images through a secondary slicing feature that allows for axial and sagittal slicing of the model. In modeling this case, the interventional team determined that a fluoroscopic view with right-sided oblique angulation to 15° would provide the optimal approach to the neuroforamen with minimal risk to infiltrating the mass or nerve root (video showing replication of recorded footage of pre-interventional session) using obliquity-controlled movements present within the anatomy sandbox's software. Angulation was

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https://doi.org/10.1016/j.inpm.2023.100180
Received 22 October 2022; Received in revised form 28 December 2022; Accepted 5 January 2023
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Fig. 1. MRI T2 imaging of the mass.
A. Axial T2 imaging. Yellow circle represents the anatomical **area** of interest
B. Sagittal T2 imaging. Arrow pointing to the anatomical **area** of interest

further approximated taking still images from the recorded session showed here and compared to fluoroscopic images prior to needle insertion during the procedure. The patient then underwent the injection with the same team that performed the pre-procedural VR session. The same angulation was recreated during the procedure with appropriate proximal spread of 1 mL of omnipaque 180 radiocontrast dye visualized prior to depositing an injectate of 2 mL of 0.25% bupivacaine and 4 mg of preservative-free dexamethasone (Fig. 2). The patient suffered no immediate adverse consequences from the procedure. At four weeks follow-up, the patient reported significant, near complete, ongoing relief of her symptoms and she went on to continue follow-up with neurosurgery for operative planning.

3. Discussion

Here we demonstrate multiple advantages for applying VR simulation as part of interventional planning and using it for pre-procedural practice that can be executed with minimal technical expertise necessary. The software and hardware utilized are commercially available with current tools and do not require additional coding to implement. This facilitated real-time, actionable modeling, where multiple users were able to view available imaging and adjust the model to fit the patient's anatomy. This information then led to actionable consequence, allowing determination of the optimal fluoroscopic angulation, which may differ from what an interventionalist might conventionally utilize for TFESIs. Furthermore,

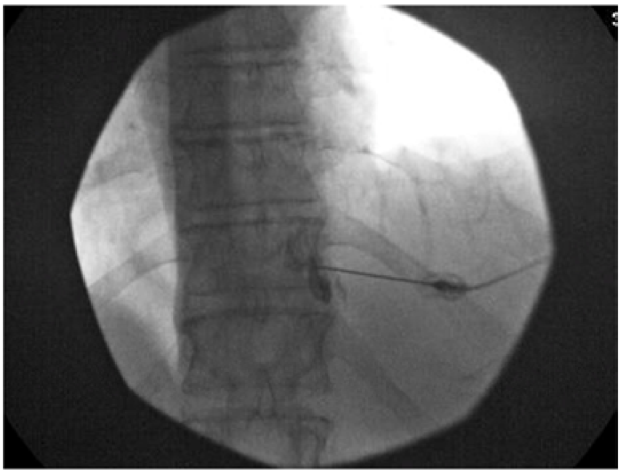

Fig. 2. Fluoroscopic image of transforaminal epidural steroid injection with radiocontrast dye to show safe infiltration of medication along the nerve root in question.

implementation of this type of simulation could facilitate rapid training focused on learners across the spectrum of experience, from first-time learners interested in modeling 3D anatomy to collaborative discussion between physicians, technologists and potentially patients.

Limitations of this approach currently involve the lack of automation with direct conversion from a patient's specific MRI findings to an interactive VR model. The procedural team here was able to compensate by recreating such findings using built-in software tools on an existing model. The currently available tools can replicate anatomic variations such as masses and osteophytes on VR simulation with the ability to modify size and simulate invasion to surrounding structures. In this particular case, the patient's mass was approximated on VR by translating its location and dimensions determined from MRI to a virtual environment. However, as the software in its current iteration lacks customizability of importing a spine model specific to the patient, this method is unable to exactly replicate the complexities of a patient's unique anatomy in simulation. As VR technology continues to develop, advances in the next generation may facilitate more exact replication of complex anatomy and even potentially automate this process in the virtual environment. While studies have demonstrated that fluoroscopy exposure and procedural duration can be decreased using supplementary training tools such as VR simulation [9,10], we propose future studies look to utilize VR for interventional planning focused on individualized cases, as it may improve patient satisfaction and outcomes.

Declaration of competing interest

Rohan Jotwani is a Scientific Advisor to *Medis Media*, but he owns no shares/financial interests with the organization and receives no funding from the organization.

Erik Wang has no conflicts of interest to report.

James Yu has no conflicts of interest to report.

John E. Rubin has no conflicts of interest to report.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inpm.2023.100180.

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Interventional Pain Medicine 1 (2022) 100088

Contents lists available at ScienceDirect

Interventional Pain Medicine

journal homepage: www.journals.elsevier.com/interventional-pain-medicine

Imaging Studies

Virtual reality for procedural education: Lumbar medial branch radiofrequency neurotomy

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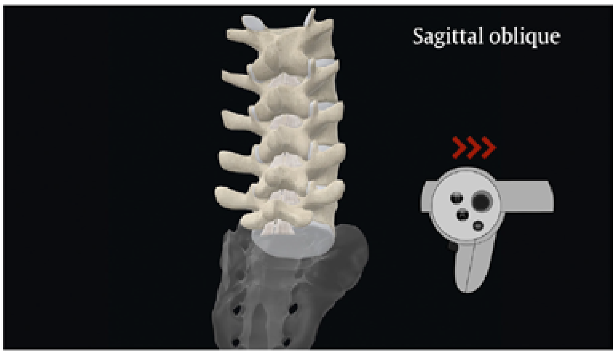
A B S T R A C T

Virtual reality (VR) simulation is an emerging tool in medical education. Simulation conducted in VR can reproduce procedural scenarios and allow for immersive interaction with anatomic models. This has the potential to improve understanding of anatomy and concepts relevant to interventional procedures.

Here, we present a "proof-of-concept" modeling of lumbar thermal radiofrequency neurotomy through cost-effective, commercially available VR hardware and software. With this technology, we can demonstrate key fluoroscopic views and needle trajectories based on specific recommendations from Spine Intervention Society guidelines. Furthermore, the learner can manipulate the model in multiple 3-dimensional axes to visualize anatomy relevant to key fluoroscopic views. Finally, the content can be exported by recording a live casting stream, thus offering an approach for future content creation and collaboration.

VR technology is an emerging educational modality that offers immersive and interactive features that may offer advantages to traditional visual teaching modalities.



Supplementary video related to this article can be found at https://doi.org/10.1016/j.inpm.2022.100088

Financial Support

The authors have no sources of financial support to disclose.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Special thanks to 3D Organon VR Anatomy for software access and support.

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https://doi.org/10.1016/j.inpm.2022.100088
Received 10 March 2022; Received in revised form 23 March 2022; Accepted 23 March 2022
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Assessing the Effectiveness of Teaching Anatomy with Virtual Reality

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ABSTRACT

When performing medical procedures, physicians must rely on their mental representations to understand complex internal structures that are not directly visible on the skin. In their training, this knowledge is acquired through the study of two-dimensional images. Currently, virtual reality (VR) is revolutionizing the teaching-learning process because it offers an experiential, low cost and easy to manage alternative for teaching anatomy. Especially if compared with performing cadaveric practices.

The objective of the study was to assess the effectiveness of virtual reality for teaching anatomy.

The design was quantitative and quasi-experimental. Three groups were defined for analysis: the self-directed practice of VR, an instructor lead practice of VR, and the control, no VR. The sample consisted of 120 medical students in their second year of the program. A descriptive research scope was defined.

The results indicate that VR had a positive impact on learning of the spatial location of anatomical structures. The students found innovation motivating and engaging.

It is necessary that medical educators establish and consolidate standards for the implementation and assessment of VR, in order to guarantee an educational experience that guarantees the achievement of learning objectives of trainees.

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ICETC 2019, October 28–31, 2019, Amsterdam, Netherlands

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ACM ISBN 978-1-4503-7254-1/19/10…$15.00
https://doi.org/10.1145/3369255.3369260

CCS Concepts

• **Hardware→Emerging tools and methodologies.**

Keywords

Educational innovation; virtual reality; educational technology; anatomy.

1. INTRODUCTION

Currently, information and educational technologies are revolutionizing the teaching-learning process. Some of these are a clinical simulation, the inclusion of augmented reality (AR) and virtual reality (VR), technologies for rapid prototyping with 3D printing, and remote laboratories for basic science. Every time there are more resources and technologies available in the market, the promptness at which schools assimilate and integrate this technology, determines a competitive advantage that can turn them into a leading organization [1]. However, this adoption cannot be an unequivocal acceptance of its value; it is essential to perform an analysis of the impact of innovations in learning before making high financial investments.

Much has been about the contribution of VR because it offers an experiential, low cost and easy to manage alternative for teaching anatomy. Especially when compared to cadaveric practices. One of its advantages is that, in a controlled environment, students can personalize their training and define their learning goals. In engineering, some studies have assessed the impact on understanding perception and spatial relationship of objects [2]. In medicine, some authors have assessed the impact of educational technology for three-dimensional visualization on the teaching of anatomy, specifically for liver segmentation [3].

A competence required in graduate doctors is to support medical decisions in theoretical, scientific and clinical knowledge about the structure and functions of the human organism [4]. The first years of training have a preponderant value in the knowledge of the human body, and the structures and systems that comprise it. The traditional curricular structure emphasizes the identification of molecules, cells, tissue, organs and systems organization, to be able to understand the interaction in the physiopathological processes [4].

2. ANATOMY TEACHING

Learning anatomy is considered by practicing physicians as a fundamental of daily medical practice [5]. Traditionally, corpse dissection has been considered as the standard method of teaching, in which students can explore the structures [6]. There has been a decrease in the presence of anatomy in the undergraduate medical curriculum, the use of dissection been reduced as well [7]. Some programs have even considered its suppression and have disseminated it in different courses. One of the factors that fueled this decision is the high cost of handling, logistics, and maintenance of anatomy laboratories [5].

Another commonly used method consists of a lecture, complemented by photographic material or images of an anatomical atlas, accompanied by descriptive texts of the different elements of the body. This strategy is based on passive transmission-reception of knowledge, and the trend in curricular design is on innovative learning models, based on four premises: equity in the relevance of teaching and research, promotion of active learning styles, contextualization of the curriculum in the community, and the mastery of learning.

Nowadays, there are more mobile applications available, in which medical students can access anatomy atlases that allow the rotation and cut of body structures [8]. The available resources applied under a carefully designed academic approach guarantee a better experience that fosters the teaching-learning process [9].

3. A CONTRIBUTION OF TECHNOLOGY ON VISUALIZATION TRAINING

When medical procedures are performed, health professionals rely on the mental representations they have to understand complex internal structures that are not directly visible on the skin. During their training as physicians, this knowledge of spatial relationships is acquired through analyzing photographs and medical images such as tomography, magnetic resonance, radiography and ultrasound [10]. These images are two-dimensional representations generated from different diagnostic technologies. The interpretation of these images is made by the mental model that the physician has to acquire from experience. It empowers him, for example, to define a surgical strategy, know the location of veins and arteries, as well as plan the specific positioning of devices. Hoffman [11] describes the use of different visualization tools and affirms that by incorporating simulation technology, students can refine the movements and procedures for multiple anatomical variations or trauma injuries.

The term virtual reality was invented in 1987 by Garb to refer to the representation or simulation of the world through symbols or figures [12]. Later, Zepel transferred the term to computing, describing it as an electronic image without a direct connection to the real world. Virtual reality is defined as an alternative environment that is composed of scenes and objects that replace reality, commonly used as lenses and visors attachments to recreate these immersive environments.

According to Sherman and Craig [13], this immersion can occur in two ways: mental or sensory, in order to create a personal experience through the use of devices and sensors that complement the scenario. Choi, Dailey-Hebert, and Simmons [12] claim that this immersion should provide the illusion of a virtual world that responds to interaction, where the user has control of the perspective and points of view.

This technology has led in recent years to educational applications and learning environments [14]. At the beginning, it was a costly technology due to the specialized equipment that was needed, as well as the little development that was taking place for specific applications in medical education. Recently different companies have developed services and stratified solutions for anatomy training and the practice of specific clinical skills.

The use of these environments for visualization and training can provide students with views of anatomical structures for them to understand the spatial relationship in the body [15]. Some studies such as Harman, Humphrey, and Goodale [16] showed that the manipulation of objects in three-dimensional visualizations, such as those available in VR, lead to faster recognition of an object if compared with a passive observation of it.

Undergraduate teaching programs have increasingly incorporated the use of technological resources. The application of VR in education is an innovation that has been perceived by students as a pleasant and stimulating experience. Some studies report the direct impact on student motivation or enthusiasm for anatomy; however, it is clear that the use of technology by itself will not have an impact on student learning.

Therefore, the objective of the study was to assess the effectiveness of virtual reality for teaching anatomy. The following research question arises: is there an advantage of teaching anatomy with virtual reality? What is the student's response to this educational innovation?

4. MATERIAL AND METHODS

4.1 Design

The design was quantitative and quasi-experimental. This design was implemented because of the convenience to work with the groups that were being taught during the semester. Although the quasi-experimental design has been criticized by the lack of random assignment into test groups because it can lead to non-equivalent groups, it has the convenience of reducing the time and resources required for logistics of assignment [17]. One of the advantages that some authors have found is that the reactions and behaviors of participants are more likely to be genuine.

Three test groups were defined for analysis: the self-directed practice of VR, instructor lead practice of VR, and the control, no VR.

A descriptive research scope was defined to understand the behavior of the variables [17]. An ANOVA variance test was used to assess the equivalency of the groups before the experiment, and the performance of students after the experiment.

4.2 Participants

The sample consisted of 120 medical students in the second year of the undergraduate medical program. The school where the study was conducted is a private university in Latin America.

4.3 Materials

After evaluating several alternatives for VR software, the 3D Organon VRAnatomy tool was selected [18]. For the hardware Oculus Rift was used, and it has an alternative two-dimensional version for tablets and mobile devices. Minitab 17 software was used for the statistical analysis.

The educational objective of this practice was for participants to identify the structures and functions of the heart. Faculty members developed a clinical case to provide context for students learning, consisting of a 23-year-old female patient, who presented to the emergency department for referring fatigue with great efforts and the history of an innocent heart murmur since childhood.

4.4 Procedure

The following research questions were defined: is there an advantage of teaching anatomy with virtual reality? What is the student's response to this educational innovation?

To answer the question regarding the advantage of teaching with VR, the equivalency of the test groups at the beginning of the study had to be guaranteed. The procedure was to administer a test where the students had to identify the anterior and anterolateral views of the heart. The participants had to name large arteries (aorta and pulmonary artery), veins (superior and inferior vena cava, and pulmonary vein), and heart cavities with the valves.

The groups that participated in VR, both the self-directed and the instructor lead practice, focused on students visualizing and manipulating 11 structures in the technology-enriched setting: heart cavities and their valves, papillary muscles and chordae tendineae, electrical conduction system of the heart, coronary arteries and veins, arteries and main veins, accompanying arteries, as well as the portal vein, superficial veins of arms and legs, upper and lower respiratory tract, tracheobronchial tree, and lungs. In the self-directed one, students defined the amount of time they would use to explore the structures, and each participant booked an appointment to use the VR setting on their own. They dedicated a mean of 60 minutes for each appointment. The instructor lead practice requires for the students to attend a defined schedule in which the expert dedicated a mean of 15 minutes to help them visualize and explore the structures of the body.

After that, the participants of the three test groups participated in the post-test where they had to identify the structures discussed in the case, on a lateral chest x-ray. Their performance was assessed according to the criteria: spatial location of the anatomical problem, description of the axis and plane within the affected system, relationship with adjacent structures, and the functional implication that entails and specific functionality. Skill was cataloged in three levels: 1) insufficient, 2) still in development, and 3) competent.

To assess student's response to the educational innovation, Tuominen et al [19] survey was used to explore the perception of participants in a virtual reality environment. This instrument uses a 7-point Likert scale, where 1 stands for total disagreement and 7 total agreement. The items evaluate interest, curiosity and the subjective experience.

5. RESULTS

The mean across groups was 5.83 structures identified, with a standard deviation of 2.1. The results show equivalency of the test groups at the beginning of the study, the ANOVA test indicates no significant difference (p-value = 0.1425). The mean by test group is presented in Table 1.

Table 2 shows the results of the post-test of the identification on a lateral chest x-ray. The results indicate that the test groups of the self-directed practice of VR and the instructor lead practice of VR had the most favorable results. The highest score was obtained on the description of the axis and plane within the anatomical system affected, with a mean of 2.46 and 2.58, respectively. The results of the ANOVA test indicate a significant difference between the score of the VR groups with the control that had no VR (p-value <0.05).

Table 1. Equivalence validation of test group

Test group	Mean	Standard deviation
Group 1: Self-directed practice of VR	5.03	2.83
Group 2: Instructor lead practice of VR	6.43	1.45
Group 3: Control – no VR	5.68	2.18

Table 2. Analysis of the image study

	Group 1: Self-directed practice of VR	Group 2: Instructor lead practice of VR	Group 3: Control – no VR
1. Spatial location of the anatomical problem of the case	2.17	2.27	1.81
2. Description of the axis and plane within the anatomical system affected	2.46	2.58	1.67
3. Relationship with other adjacent structures	2.21	2.27	1.86
4. The functional implication that entails the anatomical problem with specific functionality	2.29	2.00	1.43

The results of the student's response to educational innovation are shown in table 3. The mean in item 3 and 4 stand out, both related to the emotional part of participation with VR: I enjoyed experiencing virtual reality mean=7, and I felt involved a mean=6.96.

Table 3. Student's response to the educational innovation

Item	Mean
1. Learning to use the headset was easy for me	6.82
2. I found no difficulty in making the headset do what I wanted to do	6.21
3. I enjoyed experiencing virtual reality through the headset	7
4. I felt involved while experiencing virtual reality	6.96
5. Experiencing virtual reality stimulated my curiosity	6.82
6. During the virtual reality experience, I felt that I was in control	6.39

6. DISCUSSION

The students who performed VR activities showed better performance in the location of structures and better correlated the functional implications, regardless of whether it was the self-directed or the instructor guided group. Some authors have reported positive results in learning with VR. Nicholson and Chalk [20] experimented with a three-dimensional model of the middle and inner ear, finding that the group that used VR showed greater retention in an exam. Codd and Choudhury [21] compared the ability to identify structures of the forearm in students who used electronic resources, and a group that received traditional teaching. They found a better perception of the location of structures in the experimental group.

This study helped define methodologies and activities for the implementation of educational practices with cutting-edge technology, differentiating itself from other projects by documenting the effectiveness that it has on learning.

Training spaces should favor flexibility and personalization of educational practices, not only around teaching styles but also learning styles. One of the significant contributions is the contribution for self-direction of learning, and the optimal use of resources such as the instructor time and feedback.

Faculty in the 21st century have the challenge to become curators of content, which refers to filtering, grouping, and adapting content that complements learning. For example, the curricular structure provides opportunities to trigger the development of specific competencies. It is necessary that medical educators establish and consolidate standards for the implementation and assessment of VR, in order to guarantee an educational experience that guarantees the achievement of learning objectives of trainees.

7. ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of Writing Lab, TecLabs, Tecnologico de Monterrey, Mexico, in the production of this work.

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DESCRIPTIVE ARTICLE

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An Alternative Method for Anatomy Training: Immersive Virtual Reality

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The aim of this study was to investigate the effect of immersive three-dimensional (3D) interactive virtual reality (VR) on anatomy training in undergraduate physical therapy students. A total of 72 students were included in the study. The students were randomized into control (n = 36) and VR (n = 36) group according to the Kolb Learning Style Inventory, sex, and Purdue Spatial Visualization Test Rotations (PSVT-R). Each student completed a pre-intervention and post-intervention test, consisting of 15 multiple-choice questions. There was no significant difference between the two groups in terms of age, sex, Kolb Learning Style Inventory distribution, and the PSVT-R ($P > 0.05$). The post-test scores were significantly higher compared to pre-test scores in both the VR group ($P < 0.001$) and the control group ($P < 0.001$). The difference between the pre-test and post-test results was found to be significantly higher in favor of the VR group ($P < 0.001$). In this study, anatomy training with a 3D immersive VR system was found to be beneficial. These results suggest that VR systems can be used as an alternative method to the conventional anatomy training approach for health students. Anat Sci Educ 0: 1–9. © 2020 American Association for Anatomy.

Key words: gross anatomy education; physical therapy education; undergraduate education; spatial processing; virtual reality

INTRODUCTION

Anatomy training is the basis of health education. Slideshows with two-dimensional (2D) images are often used during anatomy training. The three-dimensional (3D) perception of organs and structures is essential for successful and effective anatomy training. For this purpose, cadavers, synthetic reconstructions, silicon, or plastic models are used (Moro et al., 2017a). The traditional view is that cadaver dissection is the best learning method for anatomy training. Cadaver dissection provides accurate information related to the shape and size of organs, bones, and muscles; however, dissection only provides a deconstructive perspective that reaches to the bone from the skin (Bogomolova et al., 2020). Complex anatomical structures that are located in deeper layers are difficult for students to imagine and even harder for the students to perceive them. Moreover, students have to study using 2D images due to the limited amount of time they are allotted to work with cadavers and the fact that they work in groups, while working with cadavers (Moro et al., 2017b).

In the study by Melguizo et al. (2020), which was conducted on undergraduate physiotherapy students, it was found that anatomy is essential for physiotherapy education (Melguizo et al., 2020). Physiotherapy students and physiotherapists need to have a thorough knowledge of anatomical structures to understand the normal motions of the body. For this reason, anatomy education is crucial for the effective treatment of patients and for students to become competent physiotherapists (Shead et al., 2016). Various teaching methodologies, such as lectures, dissection, and 2D-3D computer images, are used in anatomy training. Although dissection is the most preferred teaching method, it becomes more challenging for routine use in the educational curriculum due to the ever-increasing number of educational topics (Sugand et al., 2010). In 2011, second-year medical students' understanding of anatomy and their knowledge of anatomy were evaluated, and it was found that the students who performed dissections obtained better results

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Additional supporting information can be viewed in the online version of this article.

Received 21 August 2019; Revised 4 March 2020; Accepted 10 March 2020.

Published online ## ### ## in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/ase.1959

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(Shead et al., 2016). Visualizing a three-dimensional concept with traditional anatomical teaching is difficult (Peeler et al., 2018). Therefore, using 3D models and simulations increases the perception of functional anatomy and the localization of structures (Serrat et al., 2014). There are studies that suggest cadaver dissection is vital for anatomy learning. According to students, dissection and direct manipulation significantly increase their musculoskeletal knowledge and their knowledge of practical applications compared to passive viewing (Dissabandara et al., 2015; Peeler et al., 2018; Triepels et al., 2018). The term passive viewing is a lecture type that student does not directly contact or experience the structures. Students with low spatial ability require more direct manipulation that provides an opportunity to experience the structures and helps to facilitate learning (Jang et al., 2017).

Computer-based simulations have been used in health education since the 1970s. Thanks to the development of technology, virtual reality (VR) systems have become inexpensive and easily accessible, and they can be integrated into medical education. Virtual reality refers to a combination of a broad range of computer-assisted hardware and software that includes non-immersive and immersive VR experiences (Fealy et al., 2019). Non-immersive VR uses an avatar to represent the user on a screen and this avatar provides interactions with the virtual environment and other users (Irwin and Coutts, 2015). Immersive VR is defined as an environment composed of interactive objects that replaces the user's body as an avatar and tracks positional changes and actions on different planes. The users experience the simulation as they are in the virtual environment, and they receive feedback from the VR, which creates the feeling of immersion. Immersive VR consists of four key aspects (a virtual world, immersion, sensory feedback, and interactivity) and requires either head-mounted devices or rooms that cover the users' field of view (Sherman and Craig, 2018). Immersive 3D VR consoles provide a more realistic view than non-immersive VR consoles. These consoles provide a 360-degree interactive experience and completely isolate the individual from the external environment (Laver et al., 2018). In addition to VR applications, Augmented Reality (AR) and Magic Mirror (MM) technologies can be used in medical and educational fields. Augmented Reality is a system that uses cameras to collect real-world images and combines real-world and 3D images, allowing users to interact with the combined virtual and real environment (Jamali et al., 2015). Magic Mirror is a type of AR that displays the user's mirrored image on a screen with augmented 3D images reflected by the user's body (Kugelmann et al., 2018).

As with other quickly developing technology, VR technologies have developed rapidly and have begun to be used as a part of student-centered interactive health education in recent years (Maresky et al., 2019). In anatomy learning, VR applications represent a less expensive and promising alternative to cadaver dissection (Lee and Wong, 2014). There are also studies that suggest a 3D VR environment improves learning, especially among low spatial ability students (Jang, et al., 2017). The effectiveness of mobile-based VR devices in medical education also shows promise; however, due to motion sickness, users usually need to be stationary while using these devices (Moro et al., 2017b). In addition to education, VR systems have been used in therapeutic and diagnostic interventions in the field of medicine (Grantcharov et al., 2004; Gurusamy et al., 2009; Gurpinar et al., 2011). Virtual reality devices have been used in medical education and interventional and surgical procedures in medicine (Burdea and Coiffet, 2003; Grantcharov et al., 2004; Gutiérrez et al., 2007). While conventional education methods aim to implement visual and auditory learning aspects, during VR training, interactive learning is provided along with practical work. Many educational studies have been conducted with VR because of the combined aspect of interactive learning and practical work of VR learning methods and its possible positive effect on learning skills (Nicholson et al., 2006; Ruiz-Parra et al., 2009). Because 2D atlases and course slides are inadequate in learning about 3D structures and because cadaveric studies are not common or frequent, researchers have focused on more easily accessible 3D learning methods in anatomy (Moro et al., 2017a). Actively interacting with a 3D structure in medical education is vital to understand physical constructs and to gain a sense of confidence and familiarity with the topic (Cooper and Taqueti, 2008). This is particularly important for students in the field of surgery or anatomy (Privett et al., 2010).

The application of immersive VR within undergraduate anatomy education in physiotherapy is mostly unknown and requires ample evidence to be implemented in the curriculum. The present study aimed to investigate the effects of direct manipulative anatomy training with an immersive VR system on undergraduate students' learning compared to lectures.

MATERIALS AND METHODS

Seventy-two students who accepted and fulfilled the inclusion criteria were included in the study. This study was performed in line with the Helsinki Declaration with permission from the ethical committee of Bolu Abant Izzet Baysal University (Clinical Researches Ethics Committee 201799-131). Inclusion criteria were stereoacuity of a Titmus test at 40 arc/s (Momeni-Moghadam et al., 2011) and willingness to participate. The students who had previous VR experience and/or already commenced head and neck region anatomy classes were excluded from the study.

The stereopsis is critical and very important for VR and anatomy training (Wainman et al., 2020). Binocular vision is necessary for 3D vision, which is referred to as stereoacuity and is assessed with a Titmus test. The test is performed with special glasses designed for this purpose, and a booklet is held at 40 cm away directly at eye level (Adams et al., 2009). The booklet contains different sized images overlapping each other, and when observed with glasses, 3D images appear (Birch et al., 2008). The Titmus test was used on all students as a part of the inclusion criteria. Students were asked whether they could see a 3D object in the form of a "yes" or "no" question while wearing the glasses. The test has three subsections, which evaluate low (3,000 arc/sec), medium (1,000-2,000 arc/sec), and high stereoacuity (20-900 arc/sec) with 3D images in the booklet (Clarke and Noel, 1990; Hahn et al., 2010).

In Turkey, undergraduate physiotherapy and rehabilitation students attend anatomy courses for two semesters in their first year. Each semester is 14 weeks long and the students attend a total of five hours of anatomy training each week (three-hour lectures and two hours of laboratory experience). The first semester focuses on bony skeleton, ligaments, tendons, fascia, muscles, vessels, nerves of extremities, and the torso. The second semester focuses on head-neck anatomy, visceral organs, and neuroanatomy. The anatomy lectures are given by anatomy professors in a lecture hall with slideshows and students use the plastic real-sized models of the related structure in laboratories and attend cadaver dissections. Two of the most accepted anatomical atlases are recommended to students to supplement their class materials.

Randomization Procedure

The students were divided into VR (n = 36) and control groups (n = 36) based on the Kolb Learning Style Inventory (LSI), sex, and the Purdue Spatial Visualization Test: Rotations (PSVT-R) scores with stratified randomization.

Kolb Learning Style Inventory. The Kolb LSI developed by David Kolb in 1976 measures learning to various degrees. According to Kolb, learning styles are divided into four categories: diverger, assimilator, converger, and accommodator (Chen et al., 2005; Kolb and Kolb, 2005). The learning style of each individual is a component of these four basic forms; however, recent reviews show that the Kolb LSI is not supported by well-designed studies, and only a few studies have shown statistically significant results for some subjects (Rohrer and Pashler, 2012). In this study, the Kolb LSI was used as part of the randomization procedure because it has been found that medical students' Kolb scores may change during their medical education (Gurpinar et al., 2011; Bitran et al., 2012; Hu et al., 2018).

The Kolb LSI consists of 12 items with four options. Each item has four sentences that corresponded to one of the four learning styles, such as "I learn best from…" sentence and each ending corresponds to the four learning styles (diverger, assimilator, converger, and accommodator). The students were asked to score the appropriateness of each sentence with a rank order (most suitable sentence as "4," the second suitable as "3," the third suitable as "2," and the least suitable sentence as "1"). Based on the scores given to each option, combined scores were obtained. Responses were aligned to X-Y axes so that the sum of points in each axis represents a score on one of the four categories. In the diagram provided, according to the combined scores, the point at which the two points intersect shows the most appropriate learning style for an individual (Fig. 1).

Purdue spatial visualization test: Rotations. This test is one of the most used mental rotation tests and was used to measure the 3D perception of students in this study. Purdue Spatial Visualization Test: Rotations was developed by Guay in 1977. The test consists of 30 items. The students were told to study how the object in the top line of each question rotated and select the correct rotation from the five multiple-choice questions (MCQs) by applying the same rotation to the object in the middle line. High scores indicate high spatial perception values (Guay, 1977; Bodner and Guay, 1997).

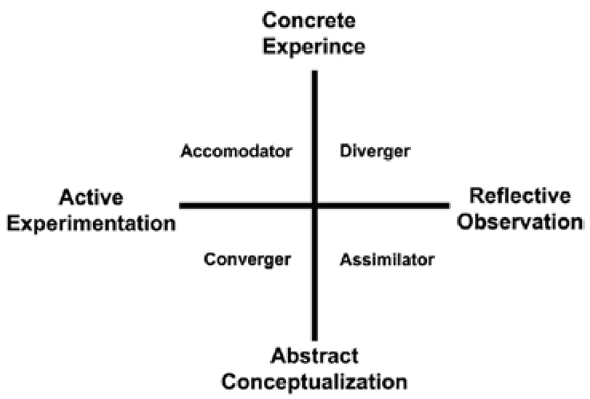

Figure 1.

On the vertical axis, the student either attempts to conceptualize an idea or theory (abstract conceptualization) or perceives experience through a new event (concrete experience). On the horizontal axis, the student can make an experience new and meaningful either by applying it (active experimentation) or reflecting on it (reflective observation). These two axes create four quadrants, each representing the four learning styles as diverger, accommodator, assimilator, converger (based on Kolb and Kolb, 2005).

Sex. Some studies have reported sex differences in scores of Mental Rotation Tests (MRT). The reported difference in spatial perception test scores between males and females resulted from the activation of different brain regions during tests. Due to this reported difference between men and women, sex distribution was taken into consideration during randomization (Voyer and Bryden, 1990; Hugdahl et al., 2006).

Outcome Assessment

A 15-question quiz was given to the students before and after the VR session and lecture. The students were given one minute for each question, a total of 15 minutes to complete the quiz.

Anatomy quiz. A 15 MCQs quiz, including questions about the anatomical structures of the head and neck region, was chosen from the anatomy and palpation lecture's question pool. The quiz was modified with the consideration of Bloom's taxonomy, but the evaluation and synthesis levels were excluded as they cannot be tested with MCQs. The questions were rated by a committee of four professors experienced in the field of head-neck anatomy between 1 and 4 scores (1 = Knowledge, 2 = Comprehension, 3 = Application, and 4 = Analysis). Bloom levels 1-2 are combined as lower-order and 3-4 as higher-order to increase interrater reliability. A total of 15 questions (eight from lower-order and seven from higher-order) were randomly chosen with an internal consistency of interrater reliability $\alpha > 0.7$ (Thompson and O'Loughlin, 2015). Pre and post-tests have consisted of the same questions, and a change in a 20% difference between the pre and post-tests was considered meaningful (Nicholson et al., 2006). The data used for reliability and validity analyses were obtained from a pilot study. The sample of the pilot study did not include the present study.

Likert scale survey. After the VR session, students' perceptions of the VR experience were rated with a five-point Likert scale item. A five-point Likert scale was used to evaluate agreement with "I enjoyed studying anatomy with virtual reality" and "It is easy to understand the location of structures with virtual reality" statements (1 = Strongly disagree to 5 = Strongly agree) (Hu et al., 2009).

Interventions. In this study, 3D Organon Anatomy® (Medis Media, Queensland, Australia) was used for anatomy training. Immersive 3D glasses (Oculus Rift®; Oculus VR, Irvine, CA) were used for VR training (Fig. 2). The anatomical region used for training was determined as the head and neck region because the second-semester students had not learned about the anatomy of the head and neck region. A presentation was prepared by taking pictures of the region used for training in a VR environment from different angles from superficial muscle groups to deep groups and bone structures. This presentation was approved by a professor with ten years of experience in manual therapy and musculoskeletal palpation. The students were given five minutes to become oriented to the application and the interface. The researcher did not provide any support unless the students experience navigation problems during the application. The evaluations were performed by a third researcher who was blinded to group allocation. The students answered 22 Yes/No questions regarding any adverse effects related to head-mounted devices based on the reference study (Ames et al., 2005).

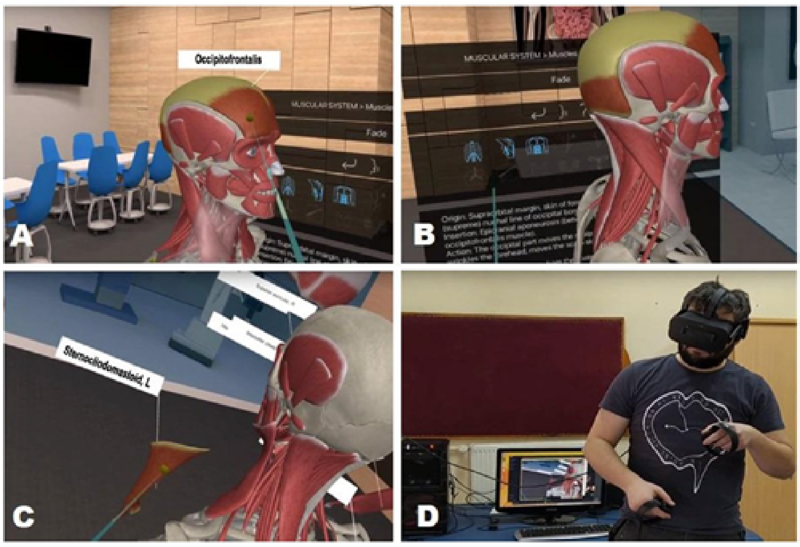

Figure 2.

Using the 3D Organon Anatomy® application for interactive anatomy training. A, Highlighting the occipitofrontalis muscle with the controller; B, Studying highlighted muscle's origin, insertion, function and nerve from the background information text; C, Detaching the sternocleidomastoid muscle and exposing the 3D structure of muscle while revealing the partially hidden underlying muscles to experience a layer-by-layer dissection; D, Third-person perspective of sternocleidomastoid muscle's direct manipulation with head-mounted virtual reality (VR) device and touch controllers.

While the control group attended a 30-minute presentation of images used in VR, the VR group received a head and neck region anatomy training for 30 minutes using a 3D virtual reality device. The students selected the related structure from the information screen and interactively studied the structures. Due to the features of the software, students not only visually examined the layers of the anatomical region but also had the opportunity to read supplementary theoretical information about the structure they viewed on the screen.

Statistical Analysis

All statistical analyses were performed using the SPSS statistical package for Windows, version 20.0 (IBM Inc., Armonk, NY). The chi-square test was used to compare the distribution of sex and the Kolb LSI between the VR and control groups. The Shapiro-Wilk test was used to test for the normal distribution of continuous variables. Normal distribution was observed for age, pre-test and post-test results, and PSVT-R scores in both groups. The paired sample t-test was used for analyzing changes in the pre-test and post-test results for each group. The independent t-test was used to analyze the differences between the post-test and pre-test scores and to analyze the adverse effects for both groups. The interrater reliability of Bloom's taxonomy was assessed using Krippendorff's alpha due to the dichotomous/nominal nature of classification (Krippendorff, 2003). The content validity of the quiz was assessed by an expert committee and internal consistency was assessed with Cronbach's alpha. The appropriateness of the factor analysis was tested with Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity. A P-value of less than 0.05 and $\alpha > 0.07$ was considered statistically significant. To achieve $\alpha < 0.05$ and $\beta = 80\%$, according to Nicholson and colleagues' study, 26 students were required for each group (Nicholson et al., 2006).

RESULTS

Seventy-two students, who met the inclusion criteria, were included in this study. There was no significant difference between the two groups in terms of age, the PSVT-R (Table 1), or sex and Kolb LSI distribution ($P > 0.05$) (Table 2). The students' age was between 18 and 22 years (mean age 19.15 ± 0.79). There were 52 (72.22%) female and 20 (27.78%) male students. The students' PSVT-R scores were normally distributed

Table 1.

Baseline Characteristics of Students in the Virtual Reality and Control Groups

Characteristics	Virtual Reality Group; n = 36 Mean % (±SD)	Control Group; n = 36 Mean (±SD)	t-test	*P*-value
Age in years	19.19 (±0.74)	19.11 (±0.85)	0.440	0.661
PSVT- R	14.19 (±4.61)	13.97 (±4.83)	0.200	0.842

PSVT-R, Purdue Spatial Visualization Test Rotations (Minimum score 0 - Maximum score 30); $P < 0.05$.

Table 2.

Distribution of Sex and Kolb Learning Style Inventory styles of Students in the Virtual Reality and Control Groups

Characteristics	Virtual Reality Group; n = 36 N (%)	Control Group; n = 36 N (%)	χ^2-test	*P*-value
Sex				
Female	29 (80.6)	23 (63.9)	2.492	0.114
Male	7 (19.4)	13 (36.1)		
Kolb Learning Style Inventory				
Accommodator	3 (8.3)	5 (13.9)	1.567	0.665
Diverger	7 (19.4)	8 (22.2)		
Converger	6 (16.7)	8 (22.2)		
Assimilator	20 (55.6)	15 (41.7)		

χ^2: chi-square test; Independent samples t-test; $P < 0.05$.

with a mean score of 46.93 ± 16.53%. Also, the students' PSVT-R scores were analyzed for the difference in sex and it was found that there was no significant difference between scores of female (46.33 ± 15.3%) and male (48.5 ± 16.76%) students ($P = 0.604$).

The Krippendorff's alpha calculation was used to assess inter-rater reliability. The results of the first four levels of Bloom's Taxonomy achieved good interrater reliability ($\alpha = 0.744$), while dichotomizing levels as "low-order"-"high-order" decreased differences and achieved high interrater reliability ($\alpha = 0.801$). Cronbach's alpha calculation was used to assess internal consistency. The results indicated an acceptable level of internal consistency for the quiz ($\alpha = 0.753$).

Both groups' post-test scores increased compared to the pre-test; however, the VR group showed a significant increase compared to the control group ($P < 0.001$). The VR group scored a mean score of 33.86% and the control group received a mean score of 39.4% from the pre-test. The post-test results for the VR group increased to a mean score of 70.13%, and the control group scores increased to a mean score of 50%. The paired sample t-test results showed that post-test scores were significantly higher compared to pre-test scores in both the VR group (70.13 ± 14.73% vs. 33.86 ± 14.86%, $P < 0.001$) and the control group (50.0 ± 20.46% vs. 39.6 ± 14.72%, $P < 0.001$). The post-test results showed an increase of more than 20% in both groups compared to the pre-test results. The pre-test results increased by 107% for the VR group and by 26% for the control group (Table 3). The difference between the pre-test and post-test results was found to be significantly higher in favor of the VR group (33.26 ± 22.86% vs. 10.33 ± 10.13%, $P < 0.001$) (Table 4).

The students from the VR group reported significantly more adverse effects than the control group ($P < 0.001$). Although the VR group showed more adverse effects than the control group, there was no significant difference between groups according to the chi-square test, except the concentration difficulty symptom, which was found to be more significant in the control group ($P = 0.047$) (Table 5).

A Pearson correlation was run to determine the relationship between PSVT-R scores and quiz scores of the VR group. There was no statistically significant correlation between PSVT-R scores and quiz scores ($r(34) = -0.23$, $P = 0.896$).

The student perceptions of the VR session group were assessed with a five-point Likert scale. 88.8% of students answered "I agree" or "I strongly agree" to the "I enjoyed studying anatomy with virtual reality" sentence with a mean score of 1.69 ± 0.92. In addition, 83.3% of students answered, "I agree" or "I strongly agree" to the "It is easy to understand

Table 3.

Comparison of Pre- and Post-Test Results between the Virtual Reality and Control Groups

Groups	Pre-test Mean % (±SD)	Post-test Mean % (±SD)	t-test	*P*-value
Virtual Reality Group; n = 36	33.86 (±14.86)	70.13 (±14.73)	–9.511	<0.001
Control Group; n = 36	39.40 (±14.65)	50.00 (±20.46)	–6.139	<0.001
Effect Size	0.388	1.129	-	-

t, paired samples t-test; total number of questions in the quiz = 15; $P < 0.05$.

Table 4.

Independent Sample t-test Result of Mean Differences between the Virtual Reality and Control Groups

Assessment	Virtual Reality Group; n = 36 Mean % (±SD)	Control Group; n = 36 Mean % (±SD)	t-test	*P*-value
Quiz	33.26 (±22.86)	10.33 (±10.13)	−6.212	<0.001

t, independent samples t-test,; total number of questions in the quiz n = 15; $P < 0.05$.

the location of structures with virtual reality" sentence with a mean score of 1.83 ± 1.05. Students' verbal feedback examples included: *"Being able to handle and inspect structures separately helps me to understand the anatomical structures"* and *"Instead of spending the same time for each structure in the lecture, I can focus on the hard to understand structures and study the related information in-depth."*

DISCUSSION

In this study, it was found that anatomy training using a 3D immersive VR system improved the test results of first-year undergraduate physical therapy students. This outcome shows a high potential for the effectiveness of immersive VR in the supplementation of anatomical education.

An important feature of VR is the high level of user enjoyment. In a study by Telner et al. (2010), 90.5% of participants self-reportedly agreed or strongly agreed with the statement, "I learn more when I have fun." Enjoyment is believed to be an essential factor in case-based learning (Telner et al., 2010). Some studies reported that most students have high enjoyment rates while learning anatomy with VR (Vuchkova et al., 2011; Maggio et al., 2012; Moro et al., 2017a). In this study, 88.8% of students agreed or strongly agreed with the enjoyment state, similar to the previously mentioned study. Self-directness is one of the key ingredients in addition to enjoyment in the success of problem-based learning in medical education (Neville, 2009; Niehorster et al., 2017). In this study, 83.3% of students reported that being able to interact with the structures helped them to understand structures.

In a study by Bairamian et al. (2019), using direct manipulation 3D-printed and VR angiogram, the two models were compared between neurosurgeon trainees, and the post-test results were significantly higher for the VR group than for the 3D-printed model group; however, the depth perception was higher for the 3D-printed model group (Bairamian et al., 2019). A systematic review reported that interactive AR sessions are more effective than passive learning (Akçayır and Akçayır, 2017). In a study by Jang et al. (2017), that was conducted with medical students in the first four years, and it was found that interactive direct manipulation in a 3D VR environment was more effective than passive viewing for learning in anatomy education (Jang et al., 2017). One of the most useful aspects of VR devices is that it allows the user to interact with the environment. The design of the present study, similar to Jang et al.'s (2017) study, allows the participant to interact with and observe anatomical structures. In this study, it was found that the pre-test results of both groups were similar, which supports randomization. Also, both groups' post-test scores increased significantly. However, the VR group scores increased significantly more than the control group. It is clear that the VR group achieved a higher degree of learning from the session and this may be caused by the immersive nature of the application or the direct manipulation of structures.

One of the issues that should be considered in studies with VR is the 3D perception of individuals. Individuals with a high perception of 3D benefit the most from VR training that requires 3D perception (Maeda and Yoon, 2013). Women's perceptual skill working in 3D has been reported to be lower than men in several studies (Peters et al., 1995; Bosco et al., 2004; Maeda and Yoon, 2013; Langlois et al., 2017); however, it was found that they use different parts of their brains for perceptual skills. Therefore, sex was taken into consideration in the randomization. In this study, 3D perception scores of students, measured using the PSVT-R and PSVT-R scores were taken into consideration during the randomization. Thus, the distribution of students' perceptions of 3D was homogenized with sex and LSI scores.

In a recent study by Maresky et al. (2019), the effect of 3D immersive VR on cardiac anatomy training was investigated and 3D immersive VR was found to be superior to conventional anatomy training methods, which is consistent with results of this study (Maresky et al., 2019). In addition to VR, AR and MM systems are alternative methods used in anatomy education. These are screen-based non-immersive systems that enable users to experience anatomical structures in combination with medical images in relation to their bodies (Chien et al., 2010; Ma et al., 2016; Kugelmann et al., 2018). In a study by Bork et al. (2019), in which MM and AR had been integrated into gross anatomy courses and their impacts on student's learning and perceptions were investigated. The post-test results of the MM group were significantly increased compared to the pre-test results, but no significant difference was found in the AR group. In addition, the group with low MRT scores received more benefits from MM compared to AR (Bork et al., 2019). In a study by Paech et al. (2018), in which both methods were non-immersive, the interactive group achieved a higher post-test result; however, the students' MRT scores were not taken into consideration (Paech et al., 2018). In this study, there was no correlation between PSVT-R scores and quiz scores. The findings of this study contradict with Bork et al.'s (2019) study (Bork et al., 2019). Therefore, further studies are needed to determine the effects of spatial ability on both AR and VR anatomy training.

In another study investigating the effectiveness of VR tablets and AR training methods were compared and no difference was found between the groups. However, it was found that VR increases the immersion, enjoyment, and engagement of students along with increased adverse effects with the VR usage (Moro et al., 2017b). Other studies have reported cybersickness-related symptoms while using VR

Table 5.

Reports of Adverse Effects in the Virtual Reality and Control groups

Symptoms	Virtual Reality Group; n = 36 N (%)	Control Group; n = 36 N (%)	*P*-value[a]
General Symptoms			
Fatigue	3 (8.3)	1 (2.8)	0.310
Boredom	1 (2.8)	4 (11.1)	0.169
Drowsiness	2 (5.6)	0 (0.0)	0.156
Headache	1 (2.8)	0 (0.0)	0.321
Sweating	2 (5.6)	0 (0.0)	0.156
Disorientation/Claustrophobia	1 (2.8)	0 (0.0)	0.321
Nausea	2 (5.6)	0 (0.0)	0.156
Dizziness	3 (8.3)	0 (0.0)	0.083
Stomach awareness	3 (8.3)	0 (0.0)	0.083
Exhilaration	2 (5.6)	3 (8.3)	0.649
Concentration difficulty	1 (2.8)	6 (16.7)	0.047[b]
General discomfort	6 (16.7)	2 (5.6)	0.137
Ocular Symptoms			
Tired eyes	4 (11.1)	3 (8.3)	0.696
Irritated eyes	0 (0.0)	3 (8.3)	0.079
Watery eyes	1 (2.8)	0 (0.0)	0.321
Dry eyes	1 (2.8)	2 (5.6)	0.562
Eyestrain	6 (16.7)	2 (5.6)	0.137
Hot/Burning eyes	1 (2.8)	0 (0.0)	0.321
Blurred vision	3 (8.3)	0 (0.0)	0.079
Difficulty focusing	1 (2.8)	4 (11.1)	0.169
Double vision	3 (8.3)	0 (0.0)	0.079
Vision discomfort	7 (19.4)	2 (5.6)	0.077
Total Symptoms	54 (62.8)	32 (37.2)	<0.001

[a]Chi-square test; [b]$P < 0.05$.

(Mosadeghi et al., 2016). It has been reported that experiencing cybersickness has an impact on immersion. Therefore, cybersickness reduces the effectiveness of VR (Servotte et al., 2020). In this study, it was found that the VR group showed more adverse effects, but this was not statistically significant. Adverse effects might have affected students' immersion; therefore, the effectiveness of the session, thus quiz scores, might have been affected.

Limitations of the Study

In the light of Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity results, a higher number of students would further support the findings. The content validity of the quiz was assessed, but validity was not verified with a valid test. The same quiz was applied before and after the session. Therefore, the motivation of students might have affected the results. For example, positively motivated students might have tried to memorize the questions and they might have focused on these topics during the lecture or using VR.

CONCLUSIONS

Virtual reality systems can be used as an alternative to cadavers for anatomy training for health students. In the present study, it was shown that anatomy training with a 3D immersive VR system might be a suitable alternative to conventional training methods. The VR system, which facilitates learning about the 3D structures of the muscles and the skeletal system, can be a unique and powerful alternative for health science anatomy education. This finding shows great promise for future applications utilizing VR, which are expected to become unique and powerful learning tools within health sciences and medical curricula.

ACKNOWLEDGMENT

The authors declare that there is no conflict of interest.

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Virtual Reality (VR) in Anatomy Teaching and Learning in Higher Healthcare Education

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1 Introduction

The implementation and use of technology is not a new phenomenon in higher education, as the use of technology creates new possibilities and challenges involving pedagogical thinking and planning [1]. Since learning using digital technology can provide a wider variation within education, as well as training for a professional career, society in general increasingly implements and adopts new technology [1, 2]. The use of technology can enhance interest among students and provide them with better conditions to understand complex information and phenomena [1].

The quality of healthcare and patient safety is prioritized within the healthcare system, and evidence-based health education is important when it comes to ensuring quality of care and patient safety [3]. Clinical practice is in a state of continuous change and has led to increasing demands in terms of student competencies and clinical skills. Higher education plays an important role in knowledge translation and in strengthening the competencies and clinical skills of students [4]. In higher education, the implementation of technology has enhanced the possibilities to teach students more complex concepts in a more efficient manner and with greater variation and visualization [5]. An example of a complex subject is the teaching and learning of anatomy. Anatomy is considered an essential science within medicine

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© The Author(s) 2023
I. Akselbo, I. Aune (eds.), *How Can we Use Simulation to Improve Competencies in Nursing?*, https://doi.org/10.1007/978-3-031-10399-5_10

and healthcare education, and anatomical knowledge is important for developing skills and becoming a competent practitioner [5–8].

Anatomy is a visual and three-dimensional (3D) science, traditionally taught in higher education through two-dimensional presentations (pictures) in books and classroom teaching. A recognized visualization technology for exploring and experiencing 3D is virtual reality (VR). Numerous systematic reviews state that technology such as VR can enhance motivation for learning and preserve knowledge and in-depth learning [9–13]. This chapter provides a general introduction to different aspects of VR and its potential relevance for increasing the quality of anatomy teaching and learning in higher education. We also provide practical insights into the development and implementation of VR-based teaching and learning of anatomy on the bachelor and master's levels in a Norwegian setting.

2 Virtual Reality: The "Whats" and "Whys"

VR is defined as "a technology which allows a user to interact with a computer-simulated environment, be it a real or imagined one" [14] and is increasingly presented as a feasible interface to promote salient, motivational, and safe environments for virtual learning [15, 16]. However, the definition of VR varies significantly in scientific literature and covers a wide range of technologies. In short, it varies from the classic, non-immersive desktop system (PC, Mac®, PlayStation®) with or without added motion tracking (Nintendo Wii® and Microsoft Kinect®) to immersive CAVE systems (multiple large projected surfaces) and head-mounted display (HMD) systems (HTC Vive® and Oculus Rift®) [17] (Fig. 1). CAVE systems have become more common due to technological advances and a desire to prioritize such systems [17]. However, our focus in this chapter is on the use of head-mounted display (HMD) systems. With HMDs, the user is immersed in the virtual environment by wearing goggles with screens for both eyes. The goggles utilize sensors that give the software exact information on the user's position and movement. Head-mounted display (HMD) systems have an additional advantage over less immersive

Fig. 1 Examples of three different types of virtual reality systems: desktop, CAVE, and head-mounted display. (Illustration: Lauritz Valved)

VR technologies in that they give students the possibility to physically move around in the environment and interact with, explore, and move objects from different angles.

Immersion relates to how effectively the computer-simulated environment replaces the perception of the real world, making the student perceive the environment through sensorimotor contingencies [18], meaning that the student's learning is shaped by stimuli and actions within the virtual environment. In this setting, it is of relevance to note the difference between 360-photo and video-based virtual experiences and computer-generated VR environments (virtual environments, VE). A photo or video captured by a 360-degree camera can be viewed in a head-mounted display (HMD) system and enables the student to visually explore the surroundings. However, this exploration is limited to the point in space in which the camera is positioned at the time of capture and the timeline of events and interactions is predefined. A virtual environment is based on 3D models, and the head-mounted display (HMD) system's position and movements are translated into the virtual environment, thus enabling the student to move around in this environment, viewing the surroundings from all positions and angles. In a VE, the timeline of events and interactions is not necessarily predefined, as the 3D models can be generated for continuous interaction.

In the Faculty of Health and Social Science at the Western University of Applied Science (HVL), we have implemented head-mounted display (HMD)-based VR in the teaching and learning of anatomy, making it possible for our students to enter a synthetic anatomical environment. We use commercially available VR software, including over 4500 anatomical structures, where the students can interact with (dissect) all of them, starting from a full-body structure or predefined substructures [19].

3 Anatomy Teaching and Learning in Higher Education

To construct knowledge about anatomical structures and how different bones, muscles, nerves, etc. are located and relate to one another is something students of both medicine and nursing have claimed to be difficult or challenging [1]. Traditionally, the teaching of anatomical knowledge within our health science programs has been introduced to students through lectures and two-dimensional pictures from books. Both primary studies and systematic reviews report that students experience learning anatomy as difficult and challenging [5–8]. The most prominent challenge to learning anatomy among students is to identify anatomical structures and understand the spatial relations between the different structures [6]. The ability to understand and perceive spatial dimensions and understand how human structures relate to one another is difficult to learn using two-dimensional resources, while anatomical structures are three-dimensional [13]. Actual anatomical knowledge and spatial anatomy knowledge has been shown to increase using three-dimensional methods instead of two-dimensional [13].

Learning concepts argue that learners must play a significant role in the educational process, presented as *collaborative learning*, meaning that students become more active and responsible for their own learning and achieving their learning goals when collaborating with peers [1, 20]. An important prerequisite in small-group collaboration is the sharing of knowledge and expertise and student ability to explain their reasoning to one another and to themselves. Promoting such cognitive restructuring of knowledge, interaction, and positive relationship within the group is essential [21–23]. Working together also contributes to developing social competencies through problem-solving and instant feedback, in addition to preparing students for a professional career, as collaboration is an essential core competency for achieving quality of healthcare [24, 25].

4 VR as Part of Anatomy Learning in Higher Education: A Practical Insight

Systematic reviews report that the use of VR has a positive impact on student ability to understand spatial and structural anatomy [3] and may be an effective resource to enhance the student's level of anatomy knowledge [5]. Another important advantage of using VR in anatomy teaching is the possibility to create a realistic learning environment that enhances student motivation and situated learning [4]. An additional reason to implement VR into the teaching of anatomy is to potentially achieve a transition from teacher-centered and passive learning (lectures) to an interactive, student-centered and exploratory learning, i.e., collaborative learning.

Since 2018, the Faculty of Health and Social Sciences at the Western Norway University of Applied Sciences (HVL) has been developing and implementing VR in anatomy teaching and learning within the bachelor's program in radiography and the master's program in midwifery. The strategic goals of the faculty are to implement and enhance the use of different learning activities, combined with technological tools, in order to enhance the ability to provide tailored and flexible education [26]. By using digital tools and a more collaborative approach within teaching, our primary goals are to enhance the learning outcomes among students, increase student motivation for learning, and, consequently, enhance the quality of the teaching.

The implementation of VR within anatomy learning and teaching was a progressive process that started with a pilot using the commercially available software 3D Organon VR [19] among first-year radiography students. The students tested the equipment in small groups of three to four students, by which one student used the head-mounted display (HMD) systems to enter the virtual environment and the other students participated by observing the VE on the desktop display. Each piloting session lasted for 60 min and concluded with a questionnaire evaluating the experience of learning anatomy in VR, the use of the software equipment, and their opinions on VR as a possible learning resource in learning anatomy as part of radiography studies. We also collected data through participant observations and dialogue.

The data indicated that the students found the VR session to be stimulating and motivational for learning. We also experienced that the discussions and collaboration within the small groups increased during the session, and the students reported a discovery of anatomical structures and coherence that they had not achieved with the two-dimensional learning resources. Data from the pilot project provided valuable knowledge about how the students experienced the VR environment. The students reported that they preferred specific tasks and guidelines to achieve learning in the virtual environment. They reported that they felt uncertain and less independent if they were left in the VE without any instructions or goals for the session. We used this feedback to develop a thematic exercise booklet that guides the students through relevant structures, including group discussion exercises, facilitating the students in using anatomical terminology orally and with positive responses from the pilot students. We experienced that both the students and teachers need to be familiar with the technology in order to enhance the potential of the technology and, consequently, the learning of anatomy.

As a result of the positive feedback and experiences from the pilot project, the faculty established the SimArena VR Lab in our simulation and training center on campus, including a total of seven HMD setups. Since then, we have established two approaches to using VR in anatomy learning and teaching in higher education: *VR-based anatomy as an integrated learning resource* and *VR-based medical simulation.*

4.1 VR-Based Anatomy as an Integrated Learning Resource

Within the bachelor's program in radiography, VR-based anatomy teaching is used as one of several digital learning resources parallel to mobile apps that utilize artificial reality (AR) models, video-based lectures, and the video recordings of fellow students. VR serves as a supplement to classroom teaching and books but has not replaced these learning resources. This pedagogical strategy is based on the theory that learning is constructed when students work with peers to generate their own knowledge and are motivated by various learning strategies [27].

Implementing VR into the bachelor's program requires both didactical and pedagogical thinking and planning, and we used the didactical relation model that emphasizes the relationship between content, learning objectives, settings, learning activity, learning conditions, and assessment [28]. In a well-planned and developed course, there is good coherence and consistency between the six different factors in this model.

The curriculum plan focuses on the essential knowledge, skills, and general competencies students are expected to achieve by the end of the program [29], while the learning objectives (LO) in higher education are based on a predefined structure of knowledge, skills, and general competence. In implementing VR, we had to consider the students' learning outcomes both during and at the end of the anatomical course. To achieve this, we have differentiated the teaching of anatomy into various topics, such as the skeletal system, nervous system, and gastrointestinal system, and organized the anatomy learning in the virtual environment into different topics. The students are taught anatomy following the structure of the anatomical syllabus reading list, creating a familiar environment for the students.

Each topic is presented in a similar way and includes a classroom lecture, independent working, and assignments. The topic lecture is given at the beginning of a new topic and is used to outline the most relevant learning outcomes for the upcoming topic, followed by a walk-through of available and relevant tools for independent working. Assignment hours are scheduled 1 week after the topic lecture. The assignments focus primarily on "general competences," entailing group assignments of practical relevance in which the students must express professional anatomical knowledge of the subject, both in writing and orally. These assignments are carried out within the virtual environment in order to enhance student knowledge and understanding of spatial anatomical structures.

By differentiating the anatomy into different topics, we can enhance student understanding of spatial anatomy by tailoring the different teaching technologies to the content. In the past, we had experienced that students struggled with the content and understanding of the relationship between the different anatomical structures, but during the assignment sessions in VR, the students are more active, collaborate more, and use more precise anatomical language in their discussions. We have also experienced that the role of the teacher has transitioned from lecturer to facilitator.

We decided to implement the VR in the radiography course in relation to each student's different assignments on each topic, and the students' tasks and guidelines were entered into the virtual environment based on the pilot findings. Each radiography class has around 30 students, and all students are given 60–120 min to complete their assignments and tasks in VR. Considerable time is spent in VR, but the student evaluations and positive experiences in relation to knowledge and skills are the main reason to continue using VR in this setting. Alternatively, VR could be made available as a separate teaching tool for students, but our experience shows that students are not very familiar with the VR environment, and it is essential to be present, facilitate the discussions, and support the practical tasks in order for the VR-based approach to be of value in the learning of anatomy.

A typical assignment for our radiography students is to be handed a 2D image and to familiarize themselves and discuss topographic anatomy in order to understand how the structures are projected on the body. During these group discussions, students are required to engage orally. In the beginning of the semester, before students and facilitators have become better acquainted, we have noticed that the students who use the HMDs initiate discussions, while their fellow students often remain silent. The students report that they are unsure about their medical nomenclature pronunciation and are afraid to reveal their limitations to other students. The awareness of being observed may potentially limit them, as many of our students are straight out of secondary school, where they are used to being evaluated during oral discussions. Because of this, we must establish a safe and positive learning environment at the beginning of each semester to help the students view the teachers as facilitators, not evaluators.

To establish a safe learning environment, the students must work under the same learning conditions. We therefore invest considerable time and resources into familiarizing the students with the technology used in the virtual environment. When there are substantial discrepancies in the mastery levels of the technology in a group of students, we have experienced that students with fewer technical skills withdraw from the learning activities and tasks and become passive and highly dependent on the presence of a teacher. It is therefore important to set aside enough time for relatively basic tasks at the start of each course, making sure that all students master the learning conditions before progressing to more advanced topics.

Students generally demonstrate their knowledge and general competencies in anatomy by means of a written exam. After implementing VR into the anatomy lectures, we have altered the exam so that the students can also demonstrate their skills. The exam now consists of a written part and a video submission in which the students present their knowledge and skills in an oral presentation. By combining different assessment methods, the students can demonstrate in-depth knowledge rather than only memorizing structures and anatomical definitions.

The implementation of VR into the bachelor's program in radiography has provided valuable knowledge and experiences for the further development and implementation of VR in other programs within our faculty. The midwifery program has worked together closely with the radiography program, learning from their experiences and having the opportunity to further develop the use of VR in higher education. The exchange of knowledge between the different educational programs has led to a different use of VR in education.

4.2 VR-Based Medical Simulation in Midwifery

Within the master's program in midwifery, we have established a VR-based medical simulation session focusing on the relationship between the female pelvis, fetus, and uterine muscle. As with other medical and healthcare programs, midwives and midwifery students require in-depth knowledge of anatomy, especially the female pelvic anatomy and fetus. A midwife must have the right competencies to facilitate normal processes in pregnancy, birth, and postnatal care, with anatomical knowledge being one of many cornerstones for developing these clinical skills and competencies [30]. Encouraging the physiological processes of intrapartum care requires a significant understanding of the interaction between the female pelvis, uterine contractions, and the fetus. To learn these skills, midwifery students need opportunities for concrete, contextually meaningful learning situations where they could improve their clinical reasoning, critical thinking, and problem-solving skills and, through these learning strategies, increase their knowledge [31].

To stimulate knowledge and understanding of the female pelvis in accordance with fetal rotation through the birth canal, we have found VR to be an appropriate learning method. By using this tool, we can demonstrate the relationship between the female pelvis, fetus, and uterine muscle in a combination that is not possible in the traditional classroom sessions. The use of HDMs enables students to follow the rotation of the fetus through the birth canal simply by adopting the fetal perspective looking down from the pelvic brim and into the pelvic cavity. The 3D effect has become essential to the teaching by replacing as many sense impressions as possible with virtual impressions and creating the illusion of being actual present in the female pelvis as a fetus. The task given to students is a laboring woman, and during the VR session, the midwifery students follow the woman and fetus through the different stages of labor. Working together in pairs, the students discuss and explore anatomical structures, use correct anatomical terms, and reflect on which procedures to initiate to promote a physiological birth. The teaching is implemented as a discussion and critical thinking among peers, demonstrating which bones, muscles, nerves, blood vessels, and structures are included in the female pelvis. Once these elements are identified, the students demonstrate how the leading part of the fetus positions itself in relation to the actual female anatomical structure or bone. During the entire session, the teacher serves as a facilitator of knowledge by participating and engaging in the discussions.

4.3 Pedagogical Strategy During the Simulation

Experience with digital resources and learning within a virtual environment varies among students of higher education, and they need to learn how to use the VR equipment at the same time as they are learning with it. It is therefore important to provide a model of learning in which students can explore the head-mounted display (HMD) systems and learn anatomy at the same time. Taking this into account, we created the sessions in the virtual reality room as a step-by-step learning experience for the midwifery students. Before entering the VR laboratory the first time, they are shown videos with the same anatomical structures as they will encounter in the virtual environment, so they can prepare and test their knowledge through multiple-choice and drag-and-drop assignments. In addition, we give them written instructions on how to use the digital tools, so they are familiar with the rules of VR before entering the learning environment. By using a scaffolding model constructing the teaching in VR, we gradually build on the student's previous experience. A structured learning scaffold offers essential support and development to participants at each stage as they acquire expertise in digital learning. Scaffolding often refers to the temporary support provided for the completion of a task that learners otherwise might not be able to complete [32].

During the first session in the VR room, the students are given a set of tasks aimed at familiarizing them with the VR environment and navigating the HDMs: how to put the goggles on properly, adjust the vision, and navigate the virtual environment using self-movement and the controller. These are the basic skills and knowledge required to participate in the future learning of anatomy. During this session, the students are assigned tasks related to the use of the HDMs that entail solving simple tasks linked to topographic anatomy. The tasks are also connected to the learning materials (videos and quizzes) given before entering the VR room. In introducing them to the virtual world by gradually building their skills and

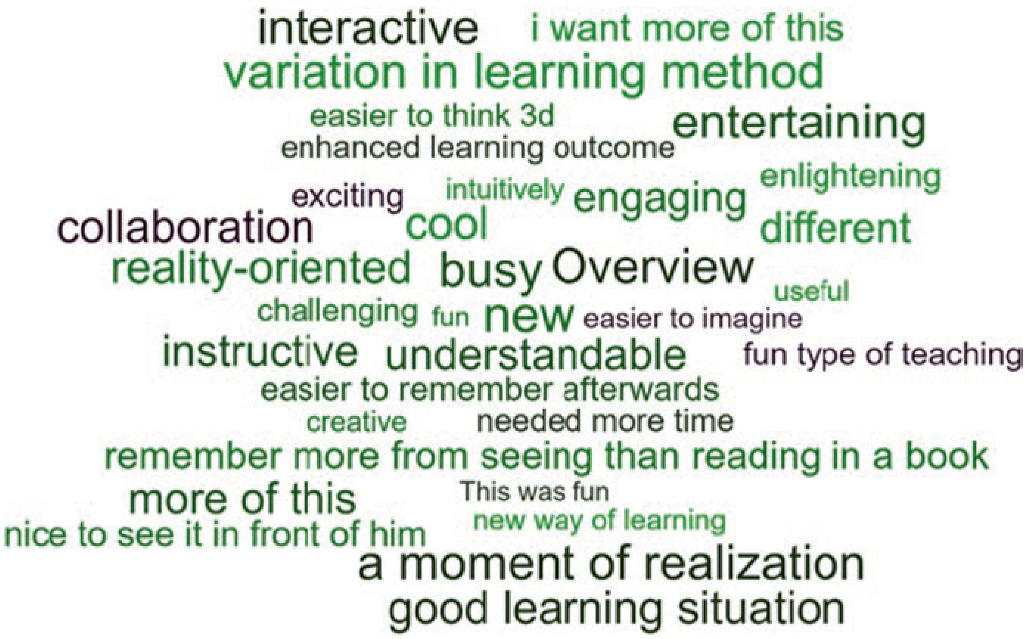

Fig. 2 Student experiences from attending VR session (translated from Norwegian to English)

competencies, we have experienced that student quickly manage to construct knowledge and understanding in anatomy using VR. The students' immediate feedback after their first session is illustrated in a word cloud (Fig. 2).

Following the initial introduction to the VR room, the next time the students attend the anatomy lecture and enter the VR room, they are familiar with the equipment and can focus on a more advanced anatomy assignment, thereby enhancing their knowledge and skills. The students are assigned a task involving a laboring woman at the start of labor. During this stage of the task, the students must find the pelvic structures and name the bones of the female pelvis, defining the pelvic inlet and border of the true and false pelvis. To understand the relationship between the female pelvic and fetus, the students must define the position that the head of the fetus would normally take in the female pelvis. This discussion provides valuable knowledge and understanding of the transverse, oblique, and anteroposterior position. The students also discover the meaning of the pelvic brim or inlet and that the pelvis is a cavity with an outlet because they can look down into the pelvis. The possibility to examine the anatomical structures from different angles gives the students the opportunity to take both the fetal perspective and midwife's perspective in relation to the pelvic inlet and outlet, gaining increased anatomical understanding. In addition to discussing and reflecting over the positioning of the fetal head, they also reflect on the flexion of the head to achieve the smallest possible diameter to pass the pelvic inlet and enter the pelvic cavity. This discussion provides the students with an in-depth understanding of how the fetus rotates and negotiates itself down the birth canal.

After accomplishing the task about the female pelvis and fetal position, the students are given further information on the progression of labor based on the woman's contractions. The students then discuss the uterine muscle and physiology of how this muscle influences the rotation of the fetus and which observations and actions support progression in normal labor. In the VR software, the students add the muscle layer to the pelvic bones, with special focus on the levator ani muscles, urogenital and anal triangle regions, and the internal and external sphincter muscles. In collaboration with fellow students, they identify the muscles included in the levator ani and discuss the rotation of the fetal head entering the levator ani muscles. This discussion enables the students to understand the rotation of the fetal head from a transverse to an oblique position and ending with an anteroposterior position in the pelvic outlet with the help of the uterus muscle and levator ani. Through the visualization of the rotation, the students become more familiar with the topographic anatomy and how to navigate using the correct anatomical terms of anterior, posterior, deep, superficial, inferior, and superior, medial, and lateral. In addition to an understanding of the fetal rotation, the students rotate the pelvis and lift the pelvis, so that the anatomical structures can be studied from different angles. This possibility in the VR software gives the students a better understanding of the different layers of the muscles and increases their understanding of the concept of deep and superficial muscle layers. The students also discover how levator ani relates to the urogenital and anal triangle and the closeness of levator ani to the internal and external sphincter muscle. Using virtual reality and the possibility to observe the pelvic muscles from different angles helps the students understand the three-dimensional structures of the pelvic muscles. The ability to take both the fetal and midwife's perspective during the laboring process increases the students understanding of interventions to promote physiological labor and interventions to reduce perineal trauma. By incorporating different subjects related to the promotion of physiological labor and clinical examples into the discussion of anatomy, we have experienced increased understanding among the students. The clinical examples, combined with other anatomy-related topics from the midwifery program, seem to increase the understanding of why knowledge about anatomy is important to becoming a competent practitioner. Studies have shown that combining relevant clinical examples with complex subjects increases knowledge and understanding, in addition to enhancing student awareness of why the subject is relevant to learn [33].

Having understood the bones and muscles of the female pelvis, the students are then asked to add the nerves involved in the birth canal. The students can then visualize how the nerve branches are linked to the pelvic muscles. The students discuss the level on which an epidural would be placed and identify the nerves that could be affected by an epidural anesthesia. The picture of the nerve branches across the levator ani helps the students understand the value of an upright position of the laboring woman. In addition, they discuss the significance of nutrition and fluid during labor, as the muscles play an important role in promoting physiological labor. During this part of the task, the students are asked to find an important anatomical landmark—spina ischia and the related nervus pudendus. The students discuss how to perform a vaginal examination and give pudendal anesthetics to block the pudendal nerve. Thanks to the spatial abilities of VR, they identify the spina ischia on both sides of the pelvic cavity and understand how to navigate in an actual situation to find both spina and the nerve connected to spina. Examining spina from both a superior and inferior position, the students discover that during a vaginal examination, they must enter the vagina posteriorly and laterally to identify spina ischia. This is something that is difficult to spot in 2D pictures from books or during a classroom lecture. After identifying spina ischia, the fetal position and station in the pelvic cavity are discussed and the rotation from a transverse to oblique position exposed to the students. Again, combining both the female pelvic and fetal position in the cavity enhances student understanding of the cardinal movements of labor.

The final step of the collaborative task in the VR room is the actual delivery of the fetal head and body. The students visualize the rotation from a transverse to anteroposterior position of the fetal head. During the task, the student with the VR goggles focuses on the fetal perspective down the birth canal, enabling the student to understand that the pelvis is spatial, with an inlet, cavity, and outlet. By navigating this cavity, the student can see how the different bones, muscles, and nerves relate to one another and how these different anatomical structures work as a whole. They discuss and reflect on different interventions to promote normal labor and, through the learning of anatomy, discover how different interventions are significant in relation to an understanding of the anatomy and physiology of the fetus and female pelvis. During the teaching session, the students work together in small groups. This is an intentional pedagogical approach. We have also recognized that anatomy is complex learning, demanding reflection through discussion and explanation. To secure the quality of the interaction and in-depth learning within the small groups, the students pair up with fellow students they already know. The teacher acts as a facilitator in the VR room, participating in the discussions and communication of knowledge. The students have reported that small-group activities create a safe environment for knowledge sharing and working with peers is more helpful than working alone due to the complexity of the subject matter. The students experience an increased understanding when interacting simultaneously in the VR room, creating a sense of togetherness. The students have also reported that the presence and availability of the teacher as a discussion partner rather than knowledge transmitter facilitates knowledge exchange within the group.

5 Summary

This chapter provide two examples of the integration of virtual reality into the teaching and learning of anatomy among students. Both approaches require a systematic utilization of student learning outcomes in the planning of anatomy lectures. The technology is tailored to the learning outcomes so that the students will gain knowledge and skills that prepare them for their future profession and clinical practice. By focusing on student learning in combination with learning activities and collaboration, the technology helps students gain understanding and knowledge.

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