

Combining computer-based training, virtual, or augmented reality with peer teaching in medical and bio-technological education

Christian Hanshans, Moritz Mourice Rick Faust

Interdisciplinary Biomedical Education and Research Center BioMed Laboratories, Munich University of Applied Sciences, Germany.

Abstract

The Interdisciplinary Biomedical Education and Research Center (BioMed) at our university offers a modern approach to biomedical education that addresses the challenge of understanding complex medical fundamentals and devices and their application in a clinical setting. This is especially relevant for our students of biomedical engineering, biotechnology, or bioengineering. The concept combines real medical devices with advanced simulation technologies and realistic training through computer-based training (CBT), virtual reality (VR), and augmented reality (AR). Peer teaching, small group activities, and tangible CBT are also incorporated into the hands-on approach, along with a focus on training with current and future technologies to prepare the students for the medical research/-engineering industry. Students responded overwhelmingly positively to the first peer-taught course that utilized VR and AR e-learning experiences, resulting also in improved exam results. This article provides an overview of the concepts used and their implementation in the biomedical engineering curriculum at our university.

Keywords: *Blended learning, virtual reality, augmented reality, education, peer teaching, computer-based training,*

1. Introduction

In a rapidly changing environment where new technologies emerge frequently, it is crucial to keep up with progress and integrate state-of-the-art as well as upcoming innovations into medical and biomedical curricula. Only by doing so can students be prepared for their future careers. Peer teaching has been shown to benefit academic performance, particularly in more practical subjects (Brierley et al., 2022), and the potential of technology such as virtual reality (VR) or augmented reality (AR) to enhance education has already been demonstrated (Wu et al., 2020). Studies have also shown that using 3D models to teach anatomy is superior to 2D learning materials (Ye et al., 2020). Peer teaching can foster teamwork, collaboration, and communication skills as students work together to teach and understand the material, which are essential skills in both academic and professional settings. When students are actively involved in teaching each other, they are more likely to retain the information, as they are forced to think about the material in a different way and explain it to their peers. However, in many cases, medical education is still taught in isolation from medical devices, neglecting the circumstances under which medical equipment (e.g. intensive care or emergency gear) is used or relying on traditional, non-interactive teaching resources like front-line teaching.

At the Interdisciplinary Biomedical Research and Training Center (BioMed), directed by Prof. Dr. med. Dipl. Ing. Christian Hanshans, a holistic concept has been developed and successfully implemented in cooperation with the University Hospital of Würzburg. It combines traditional teaching methods (such as lectures, self-study, and textbooks) with advanced digital supplements, including VR or AR-based simulations (e.g., 3D anatomy and physiology training), case-based training, anatomical models, and wall charts. The approach also includes computer-based training with learning success control, peer-guided tutorials, and the option for unguided self-study using all media. Furthermore, medical devices are demonstrated in a hands-on manner within a realistic clinical environment (such as functional diagnostics, operating rooms, or research settings). This hybrid teaching approach integrates anatomical and physiological expertise with technical skills and cross-links different classes, leading to a better understanding of complex subjects and promoting method competency. The purpose of this paper is to introduce the holistic approach and present preliminary data on student feedback obtained through evaluations, as well as compare pre- and post-intervention exam scores.

2. Concept structure

The learning concept is divided into three main subject orientations: (1) anatomical and physiological basics, (2) pathologies and medical imaging, and (3) operating principles of medical equipment and fundamentals of biomedical signal measurement. The concept is designed to provide students with fundamental knowledge in the first semesters, followed by

an introduction to how dysfunction of the previously introduced organs leads to diseases and disorders. In subsequent semesters, the focus shifts to the application of medical devices for proper diagnosis or therapy. The following paragraphs will provide a detailed description of each of the aforementioned categories.

2.1. Anatomy and physiology

As students begin their studies, they often struggle with the sheer amount of material they have to learn in a short amount of time. The courses, enriched with media and supported by tutors, provide an opportunity for students to deepen their understanding of anatomical structures and physiological processes using VR and AR. By allowing students to explore complex medical procedures, anatomy and physiological systems in a 3-dimensional and interactive way (see Figure 1), VR can provide a highly immersive experience for students. With VR or AR they get one more opportunity to consolidate the information they have already learned from lectures or books. Take the human heart, for example. You can read about its structure, how electrical impulses are generated and conducted, and when the different valves open and close. But because pictures cannot convey a sense of depth or movement your next step is to look at a plastic model to combine the 3D perspective with tactile feedback. But that still doesn't do much for your understanding of bio-mechanics or physiology. And this is where VR can be a great addition to the teaching portfolio. You can walk around a 3D animation of the heart contraction while simultaneously comparing it to the output of an electrocardiogram (ECG). This way, students learn to directly associate the state of the contraction with the spikes in the ECG. Unlike a video of these mechanisms in VR, students can scale, rotate, scroll through layers, hide and show structures like arteries, veins, or muscle fibers at will.

Another benefit of using VR and AR is that it allows for targeted teaching and learning. Bioengineering students, for example, focus more on histology and cellular processes, students of clinical optometry need to know more about the anatomy of the human eye, its diagnostic, related pathologies and clinical therapy, while the curriculum of biomedical engineering is aligned to the operating principle of medical sensors and devices.

A key factor of this learning concept is the use of different media and senses to approach the same topic. For example, as shown in Figure 1b, students can take a skeleton apart and do a practice exercise to find a particular bone. Seeing it on the AR image, they can compare and reinforce their knowledge by trying to find the same bone on a solid anatomical model and with that associating the same information with a haptic sensation.



Figure 1 a) Student while studying cardiac anatomy and physiology using a virtual reality headset. 0000b) Students using an AR software on a tablet to virtually dissect a skeleton while plastic 0000000models like the one in the display case in the background are used for comparison.

2.2. Pathophysiology and medical imaging

Various pathophysiological conditions such as tumor genesis, cardiovascular diseases, or neurological disorders are implemented in the curriculum through the use of VR, AR, or animations. This approach helps students to comprehend the underlying mechanisms and effects of these conditions on the human body. Additionally, it provides insights into the dynamics of diseases, such as the Covid-19 infection (see Figure 2).

Subsequently, students are taught about various medical imaging techniques such as X-rays, CT, and MRI, to enable them to comprehend the principles and applications of these methods and improve their ability to interpret and analyze medical images. This approach also provides a cross-reference to their prior knowledge of anatomical structures and pathologies.



Figure 2 Displaying the progression of a virtual Covid-19 infection on a patient simulated to be in a real-life training replica of an intensive care unit with real medical equipment, using AR glasses.

2.3. Functionality and use of medical equipment

Finally, students have the opportunity to apply the theoretical knowledge gained from lectures to a variety of real medical devices presented in a realistic setting. Armed with their knowledge of anatomy, physiology, and pathology, they have the basic skillset to better understand the requirements of medical devices and the needs of their users, such as doctors and nursing staff. The actual use or simulation of medical devices and procedures prepares students for their future work environment in clinics or medical device development. It is highly motivating and reinforces the knowledge acquired in previous semesters. VR is a valuable tool to simulate equipment that cannot be obtained for safety (e.g. infectious diseases or radiation), logistical, or ethical reasons (section course or visiting a real surgery or intensive care unit with an entire class), or due to financial constraints. This hands-on training can boost their confidence and prepare them for real-life situations. For instance, if they are tasked with improving medical instruments or devices, they will be better able to assess their clients' needs because they have gained experience using them.

3. Impact on student satisfaction and exam results

By providing a more interactive and engaging learning experience than traditional classroom and book-based instruction, this multimodal approach can increase student engagement and motivation. To investigate this hypothesis student evaluations were conducted. A five-point Likert scale (1 - strongly disagree, 2 - disagree, 3 - neither agree nor disagree, 4 - agree, 5 -

strongly agree) and free text fields for positive and negative feedback were used to evaluate the teaching concept. For this sample, the course "Human Biology" in the 2022 summer semester was used. This module combines the stated learning objectives of basic anatomy and physiology, pathology, and medical instrumentation. In addition, it is offered in three different undergraduate programs (Bioengineering n=26, Medical Technology n=12, and Clinical optometry n=10) resulting in a diverse total cohort of n=48 students participating (30 female, 17 male, 1 Not specified).

Many students praised the vividness that a VR or AR implementation allows. Statements like: "When I was learning the eye movements, I had a hard time understanding which muscle did what just from the script. Being able to turn the virtual eye the way I wanted and then let one muscle contract helped a lot." or "I found the animation where you could adjust the severity of the macular degeneration with the slider to see how someone sees the world with this condition very vivid" were submitted. As shown in Figure 3a, 92% of participants agreed or strongly agreed that VR helped them understand anatomy more than the lecture alone would have. The responses to the statement about the benefits of combining VR and AR with plastic models and the lecture for learning anatomy in Figure 3b were even clearer, with 94% of students agreeing or strongly agreeing.

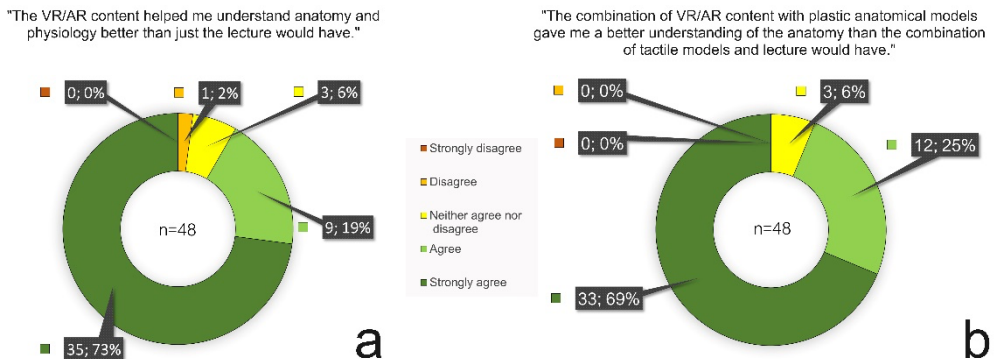


Figure 3 a) Results of the student evaluation regarding the benefits of adding VR/AR compared with the sole use of lectures for learning anatomy.

b) Results of the student evaluation regarding the benefits of combining VR/AR with the use of plastic models and the lectures for learning anatomy.

Some reported that they were more motivated to engage with the content because of the way it was delivered. They stated "It was easier to motivate me to go to the lab for tutoring than to go to the library because it feels less like learning and you have more fun in a group." and "Because looking for bones on the tablet was like playing a game, I can remember them better now." Feedback also emphasized the immersive nature of the experience. "It was kind of depressing to see the Covid patient having more and more trouble breathing. It really looked like he was sitting there on our bed struggling to breathe while his machines were

beeping.” one student wrote in their text field. The peer-teaching approach also received positive feedback. Praise like *“I liked that I could just ask stupid questions.”*, *“The patellar tendon reflex was well explained by the tutor.”* or *“The tutor’s mnemonic about the exits from the aortic arch was funny”* was given. The survey results demonstrate that the first statement quoted was not an isolated case. 73% (n=35) fully agreed and 27% (n=27) agreed with the statement “Being supervised by a student tutor instead of the professor made me feel more confident to ask questions.”

There has been negative feedback as well. Some students reported discomfort and dizziness while using the VR goggles. Three students had to stop the exercise early due to motion sickness. It has also been criticized that the university does not provide funding to make the software shown in the tutorial available to students as a campus license. Because of this, the software can currently only be used by one student at a time due to the single license, which has sometimes led to considerable waiting times. As a result, students who wanted to use the software on the tablet always had to come to the university to use the lab’s device-locked license instead of being able to use the software at home for private study.

In addition, a comparison of pre- and post-intervention exam scores was made using the bioengineering students as an example. This group was chosen because they made up the majority of those attending the tutorial and were therefore the most representative group in terms of the effectiveness of the tutorial. A peculiarity worth mentioning is that the Munich University of Applied Sciences offers the possibility for students not to take an exam, even though they are registered, without having to face any consequences. Especially in the medical subjects only a fraction (40 - 70%) of the students enrolled in the course actually take the exam. The subject Human Biology was chosen for the evaluation because this basic subject is perceived as particularly difficult by students and tends to have lower results than other subjects. In 2021 n=33 and 2022 n=30 of n=59 in 2021 and n=62 students in 2022 visiting the lectures that took the exam were compared. In both years, the exam was an online electronic exam (using Moodle) with a mixture of multiple/single choice questions, matching questions, picture marking questions, and mathematical problems. The grade average (1 to 6, with 1 being the best and 6 the worst) showed a visible improvement in the grade distribution (2021: $\bar{x}=3.50$, $\tilde{x}=3.30$; 2022: $\bar{x}=3.07$, $\tilde{x}=2.85$). Although two more students failed in 2022, the upper range of scores improved considerably. While in 2021 no student scored between 1.0 and 1.7, the number increased by 5 in 2022 (1.0 n=2; 1.3: n=1 1.7 n=2). The correlation between the introduction of the peer-taught tutorial and the improvement in grades suggests that this intervention may be particularly helpful for students in the lower to middle performance spectrum to achieve better exam results.

4. Conclusion

Overall, the use of a consistent implementation of blended learning with traditional and peer teaching, the introduction of interactive technologies such as VR, AR, case based training and real-world models or devices in a realistic environment can elevate the education of medicine and biomedical technology to a new didactical level. However, although the student evaluations and improved exam results provided a valuable first glimpse into the full potential of this broad didactic concept, further studies are needed to objectively quantify the success of the intervention on a larger scale and to identify and eliminate potential confounding factors. Yet despite the limitations this study showed that blended learning can promote motivation, comprehensive understanding, enhances social skills and collaboration and allows competence oriented teaching. In addition, students come in contact with emerging technologies (such as VR, AR) and are provided with an immersive learning experience, which can improve their understanding and readiness for real-world scenarios and their future professional career.

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