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Virtual and Augmented Realities in the Fields of Medicine and Healthcare an Analysis of Learning Effectiveness and Potential Applications – A Scoping Review

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Abstract

In recent years, the integration of virtual reality, augmented reality and extended reality into medical education and healthcare has become increasingly important. These technologies offer new opportunities for the training of healthcare professionals by creating realistic simulations and interactive learning environments. While the application of these technologies is promising, there is still a lack of knowledge about their actual impact on learning.

This scoping review analyzes simulations, VR and XR in the field of medicine and healthcare. It analyzes not only the learning effectiveness among trainees and students, but also varieties of the practical skills, clinical reasoning ability, engagement and acceptance of digital teaching methods. The aim of this scoping review is to determine the evidence on the effectiveness of simulations in learning, VR and XR in the medical and healthcare fields. A further aim is to identify potential areas for improvement in the implementation and retention of technologies. This paper consolidates the current situation and status of virtual and augmented realities internationally. A total of 36 articles were selected that reflect the use of VR/AR/XR technologies in the medical and healthcare sector.

Training in the medical and healthcare sector can greatly benefit from integrating VR/AR/XR technologies. These tools enhance spatial understanding of anatomical structures and complex procedures, such as surgery, while offering interactive virtual models that prepare trainees for clinical scenarios. Beyond improving specialized knowledge, VR/AR/XR fosters motivation and engagement, making learning more dynamic and effective—particularly in practice-intensive fields like surgery.

Background

In recent years, the integration of virtual reality (VR), augmented reality (AR) and extended reality (XR) into medical education and healthcare has become increasingly important. These technologies offer new opportunities for the training of healthcare professionals by creating realistic simulations and interactive learning environments. While the application of these technologies is promising, there is still a lack of knowledge about their actual impact on learning. Using software and technology such as Virtual Surgery Intelligence (VSI) and Microsoft HoloLens 2, 3D graphics can be generated from CT and MRI images. This can assist doctors during treatment and surgeons during surgeries. Using Microsoft HoloLens 2 glasses can be a source of information for patients (Länger 2024). Conventional surgical procedures are increasingly supported by the use of AR or MR. By projecting 3D graphics onto the surgical field, greater precision and patient safety can be achieved. One example is brain tumour surgery. MR glasses can show the surgeon possible routes to the brain tumour. This technique allows for smaller incisions, less risk of injury and patients benefit from a faster overall recovery (Roth 2021). New forms of digital therapy can be developed for pain therapy. The use of VR glasses and apps can positively influence factors such as activity, stress and sleep (Gensthaler 2023). A virtual body is provided to patients, which interacts with an artificial world. The patients observe a healthy, powerful, and strong avatar with which they can jump, run, and climb. This alters their perception of their body and pain. Additionally, the fear of movement is diminished. This phenomenon can be discussed as a potential mechanism of action of VR in pain therapy (ibd.). XR is repeatable, you can make mistakes and practice in a protected area.

Relevant terms

Virtual reality (VR) can be defined as a computer-generated reality that incorporates three-dimensional (3D) images and, in many instances, sound. The image can be transmitted via head-mounted displays, which may be either video or virtual reality glasses. There are multiple methods of interaction in virtual reality (VR). In addition to the VR glasses, the use of specific input devices is essential, including a 3D mouse, data gloves or controllers. Virtual reality (VR) has a functional role to play in several areas, including education and training, the transfer of information and entertainment. In the medical and healthcare field, virtual reality has been employed in a number of applications, including surgical training, physical rehabilitation, cognitive and brain training, pain management, and mental health (Bendel, 2019). Augmented (AR) or mixed reality (MR) can be defined as a form of reality that has been enhanced using computers. It frequently takes the form of a combination of various elements. The images of the external environment are displayed on smartphones and/or data glasses, with additional text or images overlayed. As a result, AR and MR can be employed in the field of diagnostics for the development of next-generation imaging procedures and in active learning for students and professionals. MR can also be largely virtual, in the sense of coupling with reality (Bendel 2019). Extended and Cross Reality (XR/CR): The terms "extended reality" and "cross reality" are used to describe technologies that combine elements of the real and virtual worlds in a way that creates a highly immersive experience. There are variety forms of XR. These technologies may be classified based on their position on the Reality-Virtuality-Continuum (figure 1). This demonstrates the uninterrupted transition between the real and virtual worlds (Rieke 2024).

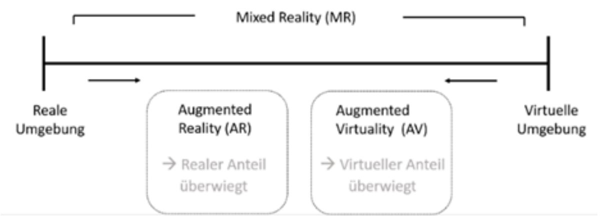

Figure 1 Reality-virtuality continuum (Paul Milgram et al. 1995)

Head-mounted Display: Head-mounted displays (HMDs) facilitate the three-dimensional illustration of visual content by employing slightly offset stereoscopic images for each eye. This is accomplished using two independent LCD displays integrated into the data helmet. These helmets may also be equipped with headphones and position and movement sensors for monitoring the users' head position. The visual and acoustic stimuli can be tracked in accordance with the head movements. HDMs displays the essential output media for virtual world (Spektrum, 2002). Internet of Medical Things: It refers to the networking of various medical devices. Portable devices, such as wearable technologies, can be utilised to transmit the measured values wirelessly to ECG monitors or directly to GPs, who can then administer appropriate treatment (Matteo, 2024). Metaverse: A metaverse defines as a combination of virtual and extended real worlds. It is not a self-contained system; rather, it is networked with reality. A metaverse can be defined as a social medium in which individuals can engage in social interaction, communication, and collaboration, as well as take action and possess property (Fraunhofer-Verbund IUK-Technologie, 2024). Avatar: In the field of computer graphics, the term refers to a two- or three-dimensional graphic representation of a person or object that is created using computer-generated techniques. The user can exert control over the avatar or engage with it (Bendel 2019).

Aim and research question

The aim of this research is to analyse the current evidence on the effectiveness of simulations, XR, VR, and AR in enhancing learning outcomes in medical and healthcare education. It seeks to identify specific learning outcomes.

The research question is: *What is the current evidence on the effectiveness of simulations, virtual reality (VR), and extended reality (XR) technologies in enhancing learning outcomes in medical and healthcare education?*

Method

The Scoping Review method was selected for systematically collect and map the extant knowledge regarding the learning effectiveness of virtual reality (VR), augmented reality (AR), and extended reality (XR) in medical education. The scoping approach allows a comprehensive examination of the research domain, including consideration of various studies regardless of their methodological quality. This is especially crucial in an evolving field such as the application of VR/AR/XR in education, where the research landscape is still developing. The scoping review was conducted according to the guidelines of Arksey and O'Malley (2005) framework. This method was chosen to provide a comprehensive review of the existing literature of effectiveness of VR, AR and XR in medical and health-related education. The aim is to capture both the breadth and depth of available research and to identify areas that require further investigation (Elm et al., 2019). This design ensures that the scoping review not only provides an illustration of the current state of knowledge, but also provides a basis for future research. The results of this review will serve as a starting step for the development of evidence-based practice and further specialist studies in this emerging area of research.

Systematic search strategies were developed and utilized in the most important databases for the literature search in this field. PubMed, Cochrane, CINAHL, Embase, PsycINFO and Web of Science were searched. Google Scholar was also used to get a quick overview in the beginning. The searching process was in the period from April to August 2024. The databases were searched for German and English-language articles in full text. The search terms used included 'Virtual Reality', 'Augmented Reality', 'Extended Reality', 'Mixed Reality', 'VR', 'AR', 'XR', 'Simulation', 'Medical Education', 'Healthcare', 'Learning Effectiveness' and 'Learning Efficacy', each of which was combined using Boolean operators to ensure the most comprehensive coverage of the topic. In addition, the reference lists of relevant studies were searched manually to identify further relevant studies. The inclusion and exclusion criteria were developed to ensure that only related and appropriate quality studies were included in the review. Inclusion criteria were: (1) original studies investigating the use of VR, AR or XR in medical education or healthcare; (2) studies investigating the learning effectiveness of these technologies; (3) publications in English or German; and (4) studies published between 2018 and 2024. Studies were excluded if they (1) focused on non-medical educational areas unrelated to medical education; (2) provided only theoretical discussions without empirical data; (3) were not published in a peer-reviewed journal; or (4) did not provide specific information on the learning effectiveness of VR/AR/XR technologies.

Data extraction

The principal aim of the data extraction was to systematically record and analyse of the results of the various applications of virtual reality (VR), augmented reality (AR), and extended reality (XR) in the medical and healthcare sector. Specific information was sought on the characteristics of the studies, the methods of intervention, the learning objectives and the content, as well as the results obtained in the respective studies. This extracted data formed the basis for evaluating the effectiveness and applicability of these technologies in the areas mentioned above. The results were presented in a concise manner in a data extraction table, with an emphasis on the essential core content. This summary of the results provided a rapid and transparent overview of the various applications of AR, VR, EX and ER in the medical and healthcare sector. Heterogeneity in the included studies was carefully identified and noted in the data collection table. These notes made it possible to understand differences in the studies about design, participant groups or settings. The influence of this heterogeneity on the synthesis of the results was considered by ensuring that significant results from heterogeneous studies were not biased in a way that would have influenced the interpretation of the overall results. The quality of the included studies was assessed using the GRADE criteria. This assessment included a risk of bias assessment, consideration of heterogeneity, sample size, duration of interventions and, if available, the duration of the long-term evaluation. These criteria helped to determine the strength of the evidence in the individual studies and to better assess the reliability of the results. To recognise potential biases, the studies were checked for completeness and validity. Particular focus was paid to funding information and possible conflicts of interest that could compromise the independence of the study results. In addition, the impact score of the respective publisher was used as an index of the scientific quality of the published studies.

Results

A total of 33 studies were selected (Figure 2) in this scoping review, focussing on the application of virtual reality (VR), augmented reality (AR), extended reality (XR) and similar technologies in the medical and healthcare branch. The included studies are (systematic) Reviews/Metaanalysis (n=12), randomised controlled trials (RCTs, n=6), non-randomised controlled trials (non-RCTs) and quasi-RCTs (n=2), quasi-experimental studies (n=5), prospective cohort studies (n=3) and intervention/comparative studies (n=5). The studies were published from 2016 to 2024 and were geographically diverse. The technologies used in the studies include a variety of VR, AR and XR devices, including VR glasses such as the Oculus Rift, Oculus Quest, HTC Vive and Samsung Gear, as well as AR goggles such as the Microsoft HoloLens and Google Glass. Specialised VR systems and simulators were also used, such as the Simantha VR Simulator and the da Vinci Skills Simulator. Metaverse platforms such as ifland and Gather.town were also used in some studies.

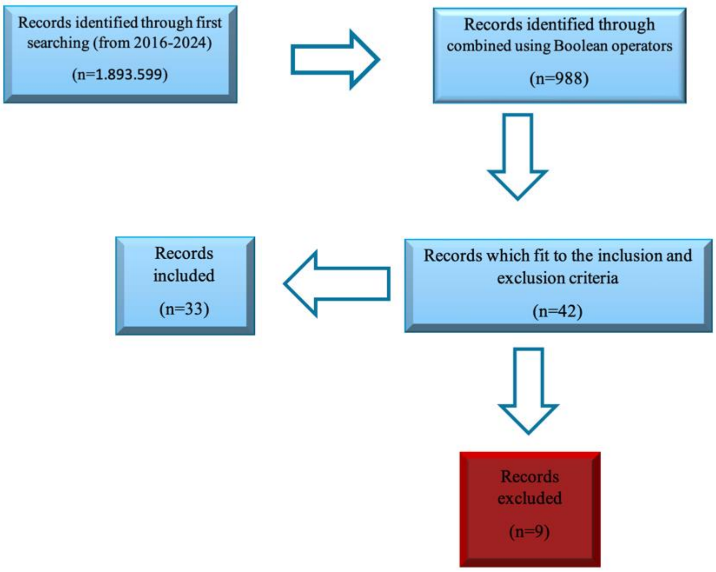

Figure 2: Flow Chart of research

Improved practical skills in surgical training

In their scoping review Dinh et al. (2023) describe the collected results of the analysis of 39 studies. The type of technology used was AR in all the studies analysed. The authors describe an improvement in diagnostic skills and the development of surgical skills by medical students and specialist staff. In all studies analysed, user feedback was positive in terms of perceived effectiveness, possibility and acceptance. Telemedical methods were also investigated in three of the analysed studies. Specialist surgeons wore AR glasses (Microsoft HoloLens 2) to livestream patient examinations to remote students. Dinh et al. (2023) found that the use of AR in surgical telemedicine and telemonitoring improves access to information. Furthermore, the use of AR facilitates counselling in various areas of healthcare (Dinh et al., 2023).

Bartlett et al. (2018) address the field of orthopaedic surgical training. In their review of 31 studies, the authors were able to demonstrate the construct validity of 16 different orthopaedic virtual reality simulators by comparing the performance of consultants and medical students in orthopaedics. The results achieved included an improvement in surgical skills, a construction of procedural knowledge and an increase in surgical performance. There was also an improvement in hand-eye coordination (Bartlett et al., 2018).

Rahm et al. (2018) conducted a direct comparison of skills in their intervention study. In their study, 20 residents and five arthroscopy experts performed a test with knee and shoulder arthroscopy tasks on a virtual reality simulator for knee and shoulder arthroscopy. The five experts only served as a reference group. The authors concluded that the assistant physicians improved significantly in training compared to the arthroscopy experts. However, the experts obtained significantly higher scores around shoulder tasks. The mean total score for the therapeutic tasks of the experts was significantly higher than the score of the residents. The use of skills-based simulator training is an effective tool to improve the basic arthroscopic skills of residents in the first years of training (Rahm et al., 2018).

Improved practical skills in the placement of peripheral venous catheter (PVC)

Andersen et al. (2021) investigated VR as an educational tool for healthcare training on peripheral venous catheter (PVC) placement. In their study, the authors compared the use of VR environments and traditional teaching methods, which was done by the control group. The authors concluded that the combination of VR with established training methods can increase competence and autonomy in ultrasound-guided peripheral venous cannulation. The proportion of successful vein cannulations was significantly higher in the VR group. By adding a VR-based training simulation to the existing curriculum, the effect of learning on medical students can be significantly increased (Andersen et al., 2021).

Improved practical skills in healthcare training programmes

Zhao et al. (2024) investigated the effect of the combination of VR on midwifery courses. A control group with traditional teaching methods served as a comparison. The control group was taught by textbooks, lectures and practical exercises. The authors concluded that there was an improvement in practical skills and an increase in knowledge within the VR group. In their long-term observation, they found that the retention of skills and long-term knowledge was better in the VR group than in the control group (Zhao et al., 2024).

In their review of seven studies Hu et al. (2023). They investigated the use of XR technologies in home care training. The studies involved the utilisation of VR applications (practice of nursing actions) and AR applications (situation simulation). All studies were aimed at teaching medical knowledge to nursing trainees. Three out of seven studies focussed on the training of nursing skills, such as endotracheal suctioning, neuroanatomy and rehabilitation. These training courses were not exclusively for home care, but also for hospital care. The remaining four studies relate more directly to home care scenarios. They include general home care and care for Parkinson's disease and associated conditions. In the studies in which AR technology was utilised, the trainees were taught using a mobile AR-based game. The trainees were instructed in the appropriate responses to be made when entering the homes of individuals from a variety of social groups for the first time. The seven identified studies have been selected for analysis in different ways. Some of them highlight the design and performance of the XR-based educational platform. Others emphasize on how the entire XR-based or training programme is designed. The authors achieved the result that, unlike VR, AR has a lower dependency on tools or other devices. In many cases, a smartphone is enough. AR could offer widespread solutions to low-cost solutions for home healthcare training, which has beneficial for developing countries in particular (Hu et al., 2023).

Improved practical skills in first aid measures

For a comparison between augmented reality and conventional methods of basic life support training (CPR), a study was conducted by Lee et al. (2021). The study included a total of 154 participants. The participants were divided equally between the XR and the conventional group. The content of the XR group consisted of two parts. An introductory video explaining the CPR steps and a VR instructor explaining the steps in more detail. The participants could independently perform techniques such as chest compressions and ventilation on the resuscitation moulage in front of them in a VR environment. The authors concluded that creating a virtual training environment can give participants a sense of realism. In the XR environment, trainees can learn various skills more effectively (Lee et al., 2021).

In another study, the authors Kim & Cho (2023) compared the effectiveness of two new CPR training methods. This included a medical VR simulation (medi-VR) and flipped learning. The participants comprised 128 firefighters. Participants were split into two groups, with the flipped learning group being a comparison group. Post-scores for CPR performance knowledge and CPR performance were significantly higher in the medi-VR simulation group than in the flipped-learning group. The post-training results showed a positive effect on learning, in terms of self-efficacy, immersion and satisfaction in the classroom, although no significant difference was found between the groups (Kim, E.-A. & Cho, K.-J 2023).

Improved understanding of anatomy

In their study, Chen et al. (2021) investigated a VR simulation using software they developed themselves. The participants were orthopaedic and neurosurgical medical students. The medical students interacted with patient-specific 3D models of lumbar spinal stenosis. Using a surgical toolkit, medical students could perform a surgical virtual procedure of decompression, specifically the removal of soft tissue and bone. The module enabled users to perform different techniques for posterior decompression and understand the anatomical areas of stenosis. The authors found improved test results in the pre- and post-test comparison. After the simulation, the average improvement in post-test results was 11.4 % for undergraduate trainees and 1.0 % for postgraduate trainees. The authors found that the VR simulation for spinal decompression was positively received by the students. Both as a learning module for Patho anatomy and for patient-specific preoperative planning. Specially it is beneficial for the first-year students (Chen et al., 2021).

In the review study by Chytas et al. (2020) several primary studies were analysed. The total number of participants in all primary studies was 1.352. Participants included medical, podiatry, physiotherapy and surgery students. Three studies investigated students' perceptions of AR. Four studies assessed examination performance following the participants' utilise of AR. AR apps, projections and AR systems were used. Various AR glasses (Microsoft HoloLens, Google Glass, Meta 2, Epson Moverio) and virtual anatomy models were used. Control groups existed within three studies. This included traditional teaching methods such as 2D images, conventional desktop-based 3D models and teaching events. The authors concluded that there was an improvement in knowledge and understanding, and an increase in practical skills among the participants. AR proved to be a useful tool and enhancement for anatomy teaching. The use of AR improved the students' understanding of the three-dimensional organisation of the structures (Chytas et al., 2020).

In their pilot study, Lin et al. (2024) investigated the use of a VR-based learning system for geriatric oral health care (Pvix VR). 50 nursing students were randomly assigned to an experimental group and a control group. The number was set at 25 participants per group. The participants in the experimental group tested the selection of action steps using the remote control on the virtual screen. During this time, voice and text system instructions were presented within the simulation. The authors concluded that even after the first round of training, the students in the experimental group showed significantly greater improvements. Likewise, after the second round of training, the experimental group showed "significantly greater improvements in knowledge, attitude and self-efficacy in geriatric oral care, as well as the intention to support oral care of older adults" (Lin, et al., 2024).

Moro worked on explaining the metaverse and its potential in the context of anatomical training (Moro, 2023). This was done through a review of 20 use cases. The studies focussed on different use cases of the metaverse. Students in one study communicated and interacted with virtual patients and applied their anatomical knowledge to clinical cases. Moro particularly emphasizes the choice of different 3D models. Students would therefore have the opportunity to choose from 1000 different but realistic 3D heart models the right one to use for their studies for that day (Moro, 2023). Students created their own hands-on activities. This involved attaching virtual labels to a skeleton, which was later shared and worked on with the cohort. The content contained in the Metaverse did not have to be created or managed by teachers. Students had the chance to create their own content and interact with it. Content included in the Metaverse does not need to be created or managed by teachers. Students can create and embed content. This made it possible to arouse the interest of the students (Moro, 2023).

Increased self-efficacy, motivation and commitment

Jacobs & Maidwell-Smith (2022) compared learning in a clinical encounter in their study. The experimental group used a 360-degree virtual reality headset (Samsung Gear). The participants comprised 89 medical students. The comparison was made with learning in a regular setting. The control group was instructed using traditional learning formats (2D videos and other non-immersive materials). Compared to the control group, no significant differences were found in the test results for the control group. However, increased engagement and empathy, as well as positive feedback on realism and communication improvement were perceived (Jacobs & Maidwell-Smith, 2022).

In their review of 62 studies Alnagrat et al. (2022), the authors focused on promoting interactivity and immersion, safety and motivation in learning, improvement of skills and knowledge and the expansion of accessibility and flexibility. Various VR glasses (Oculus Rift, HTC Vive, HP Reverb G2), VR controllers (Oculus Touch, HTC Vive Controller) and CAVE systems (Cave Automatic Virtual Environment) were used in the studies. The studies include the technologies of XR, VR, AR and MR. The authors conclude that the motivation and engagement of students was improved by head-mounted displays (Alnagrat et al., 2022). Virtual reality gives "the feeling of being physically present in a non-physical world, which is a great advantage in education. Also, being immersive in VR makes learning more motivating and engaging" (Alnagrat et al., 2022).

Glockner et al. (2023) describe the potential of VR for teaching in schools. Their study takes a closer look at the VR simulation CLASIVIR 1.0 in connection with the HTC Vive Pro. The authors conclude that an increased self-confidence of the pupils is visible. It was found that CLASIVIR 1.0 had a significant effect on the emotional level of the students (Glocker et al., 2023).

The topic of a metaverse-based career mentoring programme was examined in Kim & Kim (2023). The metaverse platform was not further classified. Their study involved 8 mentors and 43 students. The aim of the study was to offer a career mentoring programme within the metaverse that would ensure the exchange of nursing students with experienced nurses, open and honest communication through anonymity. In addition to the students' self-efficacy in career decisions, satisfaction with the platform and the programmes was analysed. The authors found that the trainees' self-efficacy in career decisions increased significantly after the Metaverses career mentoring programme compared to the baseline level (Kim Y. & Kim, M 2023). Furthermore, three key themes were derived from the focus group interviews between mentors and trainees. Open and honest communication, satisfaction with realistic communication and the expectation of an even better optimised programme (ibid.).

Chytas et al. (2020) concluded that the participants had increased motivation and commitment. Three of the seven studies investigated the potential of AR to motivate students to learn anatomy. In the questionnaire study by Kugelmann et al. (2018) the percentage of respondents who found that the AR system increased their motivation was initially 54% and up to 62% when the course extended over a period of five months. (Kugelmann et al., 2018). Ferrer-Torregrosa et al. (2015) described three out of four participants stated that AR would increase their motivation to learn anatomy (Ferrer-Torregrosa et al., 2015). The increase in this motivation with AR was statistically significant compared to the control group (Chytas et al., 2020).

Hwang et al. (2023) investigated students' perceptions of immersive learning through 2D and 3D metaverse platforms. 57 students used different metaverse platforms. A comparison was made between the platforms; there was no control group. The authors came to the conclusion that there was evidence of increased social presence, improved motivation to learn, increased collaboration and interaction among the students (Hwang et al., 2023).

Improved clinical reasoning skills

Walkiewicz et al. (2022) measured the affect and cognitive closure of medical students in their study. The participants comprised 56 students from the field of psychology. The participants were divided into two groups. One group worked with virtual patients. The second group was intended more as a comparison group. They worked with simulated patients. The authors concluded that the simulated patient was more effective for the interview skills. The virtual patient proved to be a useful teaching tool for clinical reasoning and thinking skills (Walkiewicz et al., 2022).

Improved learning performance and longer-term retention of information

Allcoat and Mühlenen (2018) investigated learning in virtual reality and the effects on performance, emotions and engagement. 99 psychology students took part in the study. There was no control group. The participants were separated into three groups, traditional, video and VR learning methods. The VR group used the HTC Vive. The authors found a significant main effect for the test. This indicates that overall knowledge improved by 23.2 % from the pre-test to the post-test. The participants in the VR condition scored significantly higher than those in the video condition. The participants in the traditional teaching method achieved the worst results of the three groups (Allcoat, D. & Mühlenen, A., 2018).

In their review, the authors Hellriegel & Cubela (2018) analysed the potential of VR for teaching in schools. They analysed various VR applications (Titans of Space, Sites in VR, 3D Organon VR Anatomy) and VR construction worlds (Google Expedition Tour Creator) in more detail. The results show improved learning skills, increased motivation and commitment, as well as a promotion of teamwork and interaction (Hellriegel, J. & Cubela, D., 2018).

Kye et al. (2021) investigated the use of metaverses in educational settings. The application included various VR platforms (Roblox, Zepeto, Classting AI, Spinal Surgery Platform). Excursions, interactive learning games, simulations and training sessions took place within virtual classrooms. Here, too, the authors came to the conclusion that an improvement in learning performance, increased motivation, commitment and cooperative skills were demonstrable (Kye et al., 2021).

Tangocci et al. (2023) investigated the use of VR and AR technology in a vocational school context. The participants comprised 116 vocational students with learning disabilities. The study focussed on the development of interactive learning scenarios on occupational safety. VR glasses (Oculus Quest) and AR glasses (Microsoft Hololens 2) were used. The Microsoft Hololens 2 should be emphasised here, as it enables interaction with real objects to obtain additional information or instructions on safe handling. Traditional, non-immersive digital learning methods (Apple iPad Pro 2) were used for the comparison group. The authors conclude that the immersive learning media (VR and AR) resulted in significantly higher levels of interest, competence and benefit than the non-immersive tablet. There were no significant differences between VR and AR themselves or in the constructs of feeling under pressure and attitude towards the learning medium (Tangocci et al., 2023).

Yang & Kang (2022) explored the use of metaverse-based simulation programmes for the care of patients with early-stage schizophrenia. The VR platform Zepeto was used. The participants comprised 58 nursing students. The Metaverse platform was accessed via mobile devices and unspecified VR goggles. The participants were divided into an MV and control group. The control group learned with using traditional online lessons. The authors found significantly higher knowledge scores, significantly improved critical thinking skills and significantly improved communication skills in the MV group (Yang & Kang, 2022).

Zender et al. (2022) investigated implementing immersive learning scenarios in a school context. Various VR glasses were used (Pico Neo 2, Oculus Quest 2). The authors present recommendations that can improve cooperation and cooperative learning among students using VR technologies. In particular, they directly address the developers of VR technologies, educational institutions, teachers, parents of students and political actors (Zender et al., 2022).

Chytas et al. (2020) came to the conclusion that the participants' learning performance improved (Chytas et al., 2020). Four of the seven studies investigated the academic performance of the participants. In three of the four studies, the researchers found AR to be significantly superior to traditional educational tools (Ferrer-Torregrosa J et al., 2016; Ferrer-Torregrosa et al., 2015; Küçük et al., 2016). The studies by Ferrer-Torregrosa et al. (2015, 2016) and Kücük et al. (2016), included 211, 171 and 70 participants respectively. They showed that AR led to significantly better academic performance than the other methods investigated. It was generally found that AR has a positive effect on students' academic performance. Furthermore, AR can be considered an effective tool for teaching anatomy (ibid.).

Lin et al. (2024) achieved improved learning performance among the participants in the experimental group. The authors assume that the knowledge and self-efficacy of nursing students can be improved by a single training session with the VR learning system. Furthermore, the authors emphasise that repeated training may be required twice to support nursing students' attitudes toward geriatric oral health (Lin et al., 2024).

Moro (2023) identified factors that can be favourable for using VR for station-based teaching. The author cites the result with the example of a class with hundreds of pupils. Pupils could be divided into small groups for a 5-minute practical activity. By using MR and virtual 'stations', teachers would no longer be limited to the size of a room. Teachers could keep groups far apart. Similarly, groups could be kept closer together to encourage and facilitate discussion between groups (Moro, 2023). The author mentions the online game Second Life as an example of the use of metaverse elements for virtual wards. The application of Second Life has already been used for medical training. Here, students had the opportunity to work together with other students or compete against them (ibid.).

Uslusoy et al. (2024) found the use of metaverse learning environments. The participants were 42 medical students. The participants were divided equally between the experimental and control groups. The latter only learnt through online training. In a created virtual classroom, the students were instructed through videos, PowerPoint presentations and AR applications (via QR code application). A virtual 3D model with a patient, a patient bed and a nurse were used in this study. The lectures were held interactively in this environment. Before the intervention, the mean values of both the experimental and control groups showed no significant difference. After the intervention, however, there were statistically significant differences. The authors found that there was a significant difference between the groups in terms of motivation to learn and academic performance (Uslusoy et al., 2024).

Alnagrat el at. (2022) found the result that the use of VR headsets to perform immersive VR in the classroom would increase students' learning performance. Educators emphasised that the use of a headset would improve the experience of trainee surgeons in the operating theatre. The reasons given for this were close-ups and 360-degree views through the VR headset (Alnagrat et al., 2022).

In another study, Kim & Kim (2023) investigated the presence and effectiveness of online learning on a metaverse platform. The participants comprised 48 students, with no control group. Through the metaverse platform (Gather.town), group discussions, virtual classrooms/offices and interactive activities took place. The authors found a significant improvement in online presence and an increase in learning effectiveness. There were significant differences in three subscales: classroom presence, social presence and cognitive presence. Using the Metaverse platform had a positive impact on online usability skills and improved the efficiency of online learning (Kim Y. & Kim, M., 2023).

In their study, Pickering et al. (2022) identified differences in learning gains between a mixed reality application and screencasts in neuroanatomy. The participants consisted of 200 medical students. The control group included traditional learning methods using a character screencast (non-interactive learning resource). The authors found that both the MR application and the screencast groups demonstrated significantly improved knowledge retention. The screencast group showed a greater effect on knowledge retention than the MR application (Pickering et al., 2022).

Improved acceptance of digital teaching methods

Speidel et al. (2021) examined digital trends in medical education before and after the COVID-19 pandemic. The participants included teachers (SS 2019: 56; SS 2020: 64) and students (SS 2019: 163; WS 2020: 285). The study focussed on the use of digital teaching platforms (online courses, webinars, virtual seminars), changes in teaching methods (adaptation to online formats, use of e-learning resources, interactive digital tools) and digital communication (video meetings and email communication). The authors concluded that the acceptance of digital teaching methods has increased among the participating students. Furthermore, the variability in the learning experience was an important point for the students. The students' increased confidence and motivation to learn indicates that immersive technologies can not only improve learning. Increased student engagement and satisfaction would also be affected (Speidel et al., 2021).

Discussion

Training in the medical and healthcare sector could benefit considerably from the integration of VR/AR/XR technologies. The studies show a significant improvement in the spatial understanding of anatomical structures and complex procedures such as surgery. These technologies allow trainees and students to interact with a variety of virtual organ models, for example, which improves understanding and preparation for real-life clinical scenarios. The use of VR/AR/XR in training not only promotes specialised knowledge, but also increases the interest, motivation and commitment of trainees and students, as the virtual representation of subject areas makes teaching more varied and interesting.

The use of these technologies in education and training has the potential to increase the motivation and commitment of participants. This is particularly beneficial in areas that require a high level of practical expertise, such as surgery.

Both AR and VR have proven to deliver superior learning outcomes compared to traditional methods, with faster and more significant improvements in knowledge, skills, and self-efficacy. Immersive experiences in these technologies foster increased motivation, commitment, and self-efficacy among learners, further enhancing their engagement (Dinh et al., 2023; Bartlett et al., 2018; Andersen et al., 2021). Additionally, they contribute to improved long-term knowledge retention and the preservation of practical skills, solidifying their effectiveness as educational tools (Zhao et al., 2024). AR, in particular, stands out due to its accessibility, e.g. requiring only minimal hardware, such as a smartphone, making it a cost-effective and scalable solution for applications like home healthcare training (Hu et al., 2023). Its impact is especially evident in anatomy teaching, where it facilitates a better understanding of the three-dimensional organization of structures (Chytas et al., 2020). AR and VR enable faster learning outcomes, with experimental groups showing greater improvements even after initial training rounds (Lin et al., 2024). Finally, the high perceived effectiveness, feasibility, and acceptance of these technologies among users highlight their practical value and adaptability for diverse educational and training contexts (Moro, 2023; Madiwell-Smith, 2022; Alnagrat et al., 2022, Kim&Kim, 2023; Tangocci et al., 2023). These findings collectively underscore the potential of AR and VR as transformative tools for enhancing learning experiences and outcomes. The findings underline the transformative potential of AR and VR in educational and training contexts, showcasing their ability to enhance both cognitive and practical outcomes. The improvements in knowledge acquisition, skills development, and long-term retention highlight these technologies as superior alternatives to traditional teaching methods. The increase in motivation, engagement, and self-efficacy further reinforces their value in fostering an active and committed learning environment. Particularly notable is the accessibility of AR, which requires minimal hardware and offers cost-effective solutions for diverse applications, such as home healthcare training. This positions AR as a scalable option for broader implementation, especially in resource-constrained settings. Its success in anatomy education underscores its strength in visualizing complex spatial relationships, enabling students to achieve deeper understanding and faster learning outcomes. The positive reception by users reflected in their perceived effectiveness, feasibility, and acceptance emphasizes the practicality and adaptability of AR/VR solutions. However, the reliance of VR on specialized devices may limit its scalability compared to AR. Future research should explore ways to reduce these barriers while investigating long-term impacts across broader demographics and disciplines. Despite the valuable insights provided by this scoping review, there are several methodological and content limitations that need to be considered when interpreting the results. Some of the included studies had small sample sizes and a limited geographical distribution. This limits the applicability of the results to other contexts and populations. Another problem was the heterogeneity of the trials. The differences in the trials, especially the fact that many participants came from different medical specialties, made it difficult to compare the results. In addition, many studies lacked long-term analyses, or the analyses covered only short periods of time.

Conclusion

In conclusion, AR and VR technologies present a transformative opportunity to enhance education and training in healthcare, combining engagement, accessibility, and effectiveness to address diverse learning needs. However, their success depends on the careful identification of appropriate use cases and the thorough preparation of educators to employ these tools effectively. To maximize their potential, AR and VR should be strategically integrated into the curricula of health professions, ensuring that both learners and instructors are equipped to leverage these innovations for optimal learning outcomes. The use in performance-oriented areas as well as in the area of communication and empathy exercises shows how versatile XR can be.

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