Commentary

Metaverse in medical education

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Medicine is an ever-changing landscape, forced to continuously evolve in response to all challenges that come with constant advancements in the pursuit of better patient care. This has paved the way for implementing novel techniques, such as minimally invasive surgery and robotic surgery, minimizing complications, reducing hospital stays, and improving patient outcomes. This has increased the burden of the knowledge and skills that students and residents must acquire throughout their training. Despite this, increased considerations for patient safety result in limited clinical exposure, providing a glaring contrast between the knowledge and skills that trainees need to acquire and the opportunity and time available to acquire them. The coronavirus disease 2019 (COVID-19) pandemic has exacerbated this problem. Restrictions on controlling disease transmission have further constrained learning opportunities. This can prove detrimental because medical education is fundamentally rooted in face-to-face meetings as a means of learning.

However, the introduction of the metaverse may solve these challenges, perhaps initiating another evolution in medical education. The term metaverse, first coined in the 1992 science fiction book *Snow Crash* by Neal Stephenson, was described in the story as a virtual world in which people can communicate with each other through digital avatars. The characters in the story engage in activities in an interconnected virtual world designed as an alternate reality for its users.[1] This article discusses what metaverse is, its possible applications in medical education and medicine, and the concerns regarding its implementation to highlight the potential role of metaverse in medical education.

Definition of metaverse

Mark Zuckerberg explained the concept of metaverse as an integrated and immersive virtual ecosystem with seamless barriers between reality and virtuality where people can participate in a shared simulated experience through their personal avatars. This shared immersive virtual space is rooted in augmented reality (AR) and virtual reality (VR),[2] which can be accessed using AR and VR devices. VR is a technology capable of immersing a user in a virtual environment, whereas AR uses technology to project virtual presence into reality, superimposing it onto the real world. Metaverse is an integrated and connected virtual space accessed through VR/AR devices and can exist as a form of VR or AR. It can be considered a scaled-up and extended version of both VR and AR, where a user using VR/AR devices could experience a virtual world only they could interact with. In contrast, the metaverse allows users to experience a shared virtual world that multiple people can interact with and experience simultaneously. The Acceleration Studies Foundation,[3] a representative of metaverse research, categorizes metaverse into four types: lifelogging, the mirror world, and the aforementioned AR and VR. Lifelogging is the technology used to capture, store, and share personal experiences and information about a user's everyday life through social media platforms. The mirror world, as the name suggests, is a virtual mirrored version of our world equipped with additional information such as global positioning systems (GPS) or Google Earth. The four concepts are then connected and converge to form the metaverse.

Metaverse learning provides programmable, controlled, and safe learning environments in medical education. It can simulate classrooms and laboratories, enabling teachers and students to participate in learning similar to real-world settings through their avatars. Additionally, it can provide medical procedure training that allows trainees to practice continuously without safety concerns and prepare trainees before performing them on actual patients. Metaverse learning is also less resource-intensive

Table 1. Advantages and disadvantages of metaverse-based learning

Advantages	Disadvantages
- Time efficient - Facilitates distant learning in real time - Provides various interactive learning tools with 3D capabilities - Simulating multiple different medical procedures in a safe, controlled, and repeatable environment without compromising patient safety - Simulates a more immersive training experience	- Substantial initial cost of development - Lack of haptic and emotional feedback for students - Potential security, privacy, and ethical concerns - Possible motion sickness after prolonged use - Requires reliable high-speed internet network infrastructure

than its traditional real-world counterparts owing to the significant cost constraints in operating and maintaining laboratories and training devices. Further advantages and disadvantages are listed in Table 1.

Possibility of metaverse-based medical education

As the use of VR and AR has become more widespread in medical education, it is exciting to consider how the metaverse can potentially revolutionize the field. Classical classroom lectures featuring PowerPoint slides and textbooks can be simulated in a metaverse, with teachers and students equipped with their personal 3D models depicting the subject, essentially turning it into a laboratory environment. While teachers use large 3D models to demonstrate concepts, students can manipulate smaller, more detailed models to strengthen their understanding of a subject. Metaverse can be programmed to provide further information regarding the manipulated structure, highlighting how certain structures function and animate complex systems and pathways. This ability to visualize structures in 3D may impact knowledge acquisition and retention in students studying anatomy.[4] This was illustrated in a physiology course where a group of students using AR to learn cardiac physiology got higher scores and could illustrate cardiac physiology better than students learning using traditional methods comprising lectures, textbooks, and images.[5] The same concept can be applied in case presentations and multidisciplinary team meetings. A forum of physicians from various disciplines can benefit from these capabilities and bridge the knowledge gap between different fields.

As medical education increasingly relies on simulations, the objective structured clinical examination (OSCE) has been widely adopted for assessing students. While the assessment is conducted on real simulated patients, the process of studying and practicing for the exam is rooted in roleplaying the patient carer between students in a group. This dedicated group-centered learning approach may not always be feasible, especially with numerous other assignments and exams. An "OSCE Mock Exam" set in the metaverse can be the solution. Problem-based learning, another staple in medical education, relies on clinical cases as the point of discussion. Metaverse can help simulate virtual patients more realistically and engagingly to deliver clinical scenarios commonly presented in the text. The programmable nature of the metaverse also allows institutions to develop comprehensive programs suited to their curriculum requirements. An institution using an integrated block curriculum can develop fully integrated programs of the human body systems, providing all the necessary anatomy, physiology, and pathophysiology knowledge at the beginning of the block and later illustrating diagnoses and treatments of the diseases. Students may also use the program as a study guide, helping them focus on the topic and minimize the time spent learning irrelevant materials from other sources.

The ever-increasing burden of skills that students and residents must acquire during their training years, coupled with increasingly limited hospital exposure owing to patient safety concerns, may result in poor performance and lead to medical errors.[6,7] Thus, it is essential to provide an environment capable of replicating clinical scenarios in which trainees can safely and repeatedly practice different medical procedures before performing them on a patient. The immersive and programmable nature of the metaverse provides an optimally safe, controlled, yet customizable training environment. Although mannequins and task trainers, the mainstay of simulation-based training, can provide high-fidelity haptic feedback, they are single-purposed and unable to simulate patient interactions. Instead of only going through the motions of a procedure, trainees can indulge in a more comprehensive and realistic experience and follow a clinical scenario from the initial patient assessment to perform the procedure. This is especially helpful in essential yet complex training such as advanced trauma and cardiac life support. In addition, mannequins and specific trainers are also resource-intensive and require significant costs and manpower to arrange and operate.[8] Metaverse-based training is particularly beneficial for surgery training, with the constant development of techniques with increasing difficulties paired with cost-ineffective training methods amidst the limited training hours. These considerations further push the claim to shift toward a more cost-effective alternative in metaverse-centered training. Various impelentations of VR/AR are already used to train different procedures, ranging from basic skill to advanced surgical techniques. Several studies have shown comparable or better learning outcomes in certain procedures.[9–11] Metaverse-based learning being more accessible than traditional training methods can increase the amount of training outside the operating room (OR), helping shorten learning curves, and improving OR performance, especially for novel surgical techniques.[12]

Current use of metaverse in medical education

While the possibilities seem enticing, various implementations ranging from knowledge transfer to skill training have mostly been experimental. These are confined to studies and trials that compare their efficacy with traditional teaching modalities. Anatomical education is one of the most popular medical education programs. Although the traditional practice of cadaver-centered anatomy learning aided by atlases has been used for centuries, it still has ethical issues.[13] Limitations due to decomposition and preservation techniques, such as changes in appearance and color, might hinder the ability to learn, not to mention the resources needed to preserve the cadaver itself.[14] Some studies have also documented the effects of cadaver dissection on students' emotional states, including anxiety and guilt.[15,16] While the sensation of real tissue manipulation and the multiple sensory feedback from cadaver dissection may not be replaceable, the metaverse can provide the necessary spatial visualization of structures from multiple viewpoints in 3D that atlases are incapable of. A German institution developed an immersive VR program to simulate an OR consisting of a dummy with precise human anatomy.[17] Students can then interact with the dummy as they interact with a real cadaver. Further information regarding the structure was provided when students held certain anatomical structures.

In medical training, VR/AR has already been widelys used to train for different procedures depending on the institution. These implementations are listed in Table 2.[18–28] In addition to training, VR/AR has been utilized in planning minimally invasive surgical procedures. The complex nature of some cases may require 3D models to better illustrate the anatomy of patients and help plan an optimal surgical approach. Data from routine preoperative imaging modalities can create a personalized 3D model, allowing surgeons to simulate surgical approaches and ultimately deliver better care. The models generated can also be viewed with AR technology in the OR, helping to visualize anatomical structures that would otherwise be difficult to localize owing to the restricted field of view and lack of spatial perception of laparoscopic systems. The possibility of using AR models as a real-time guiding tool for incision and instrumentation is currently being explored in neurosurgery[29] and orthopedics.[30]

The introduction of the metaverse during the COVID-19 pandemic geared its development toward providing a new social communication platform. The widely used teleconference apps such as Google Meet and Zoom have been shown to cause "zoom fatigue," which refer to feelings of emotional exhaustion due to a lack of social connection. Factors such as only seeing someone's face closely through the webcam without seeing their body movements or gestures contribute to this feeling.[31] The use of metaverse-based platforms with avatars can help alleviate these factors. A group of orthopedic surgeons held a virtual meeting in the metaverse to discuss clinical cases (Figure 1). Their discussion was aided by a 3D model of the patient's scapula, with which they could manipulate and interact with the model together.

The Seoul National University, Bundang Hospital, in South Korea showcased an even more exciting implementation.[32] Utilizing a smart OR, they held a virtual surgical training program as part of the Asian Society for Cardiovascular and Thoracic Surgery conference (illustrated in Figure 2), where participants joined a virtual conference room to observe lung cancer surgery.

The smart OR used multiple 360-8k-3D cameras to broadcast an unobstructed 3D view of the OR in its entirety. Instead of observing only a limited surgical field in traditional surgery footage, observers

Table 2. Implementations of metaverse-based learning in medical training

Field	Use of VR/AR	Institution
Neurosurgery[18]	Endoscopic neurosurgery Cranial tumor surgery Microvascular decompression Cerebral aneurysm clipping	Mount Sinai Hospital, Toronto, Canada Jichi Medical University, Tochigi, Japan Chinese PLA General Hospital, Beijing, China Kepler University Hospital, Linz, Austria
Maxillofacial surgery[18]	Orthognathic surgery Fixation of mandibular fracture	University of Basel, Basel, Switzerland Morristown Medical Center, Morristown, New Jersey, USA
General surgery[18]	Hepatobiliary surgery Open hepatic surgery Laparoscopic salpingectomy Laparoscopic pancreatectomy	University of Strasbourg, Straosbourg, France Paul Brousse Hospital, Villejuif, France Copenhagen Academy for Medical Education and Simulation, Copenhagen, Denmark Division of Gastroenterological and General Surgery, Showa University, Tokyo, Japan
Urology[19,20]	Transurethral resection of the prostate Ureteroscopy/cystoscopy	Linköping University Hospital, Linköping, Sweden Beijing Shijitan Hospital, Capital Medical University, Beijing, China
Cardiothoracic surgery[21]	Video-assisted thoracic surgery Robotic video-assisted thoracic surgery	Copenhagen Academy for Medical Education and Simulation, Copenhagen, Denmark Hospital Copa Star, Rio de Janeiro, RJ, Brazil
Ophthalmology[22]	Vitreoretinal surgery Cataract surgery	Nancy University Hospital, Nancy, France Imperial College London, London, UK
Otothinolaryngology[23]	Myringotomy Cochlear implantation	University of Western Ontario, Ontario, Canada University of Wolonggong, NSW, Australia
Orthopedics[24]	Arthroscopy Arthroplasty	Imperial College London, London, UK Nancy University Hospital, Nancy, France
Anesthesiology[25–27]	Bronchoscopy	Lausanne University Hospital, Lausanne, Switzerland Geneva University Hospital, Genève, Switzerland
	Regional anesthesia	University Hospital RWTH Aachen, Aachen, Germany
	Cricothyroidotomy	Baylor University Medical Center, Dallas, Texas, USA
Cardiology[28]	Cardiac catheterization	Terrence Donnelly Heart Centre, St Michael's Hospital, Toronto, Ontario, Canada
	Coronary angiography	Karolinska Institutet, Stockholm, Sweden

could see all the monitors and instruments used in the procedure. The nature of the 3D footage, in which scenes change as participants turn and move their heads, adds another layer of immersion to the experience.

Metaverse in medicine

Telemedicine has become a prominent example of the possibilities of the metaverse in healthcare. The remote healthcare provision enables patients to receive consultations, diagnoses, and treatment regardless of geographical barriers, eliminating the need for travel. This is particularly helpful in Indonesia, where specialists and consultants are limited to certain regions. Initial assessments and tests can be performed at a local center and subsequently reviewed by a specialist at a higher-level center. As discussed earlier, the metaverse-based case discussion can make the handover more effective, helping the specialist decide whether the patient requires referral to a tertiary center island, thus eliminating unnecessary travel costs for the patient. Although conventional telemedicine uses conference applications for communication, it has limitations in providing adequate care, restricting its usage to patient communication. In contrast, telemedicine in the metaverse provides a more immersive experience, enhanced patient care and consultations, and improved communication effectiveness. A virtual consultation room with a specialist walking a patient through the assessment, diagnosis, planning, and treatment procedures, which includes illustrations, models, and even demonstrations, would help patients better understand their condition and reduce their anxiety.

Several concepts have been proposed regarding how the metaverse can shape future health services. One of the key features is the live augmentation of

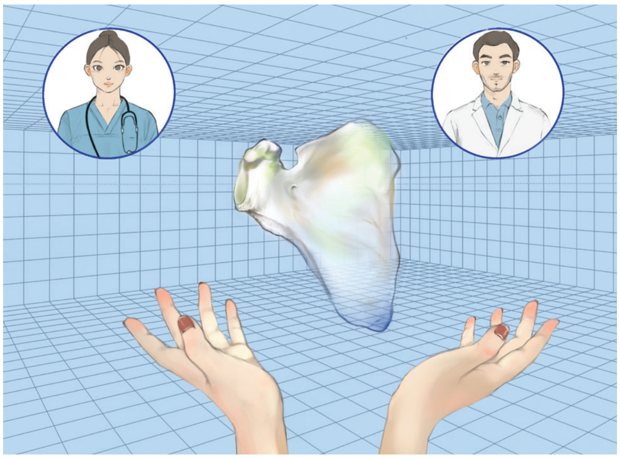

Figure 1. Metaverse usage in orthopedic case discussions

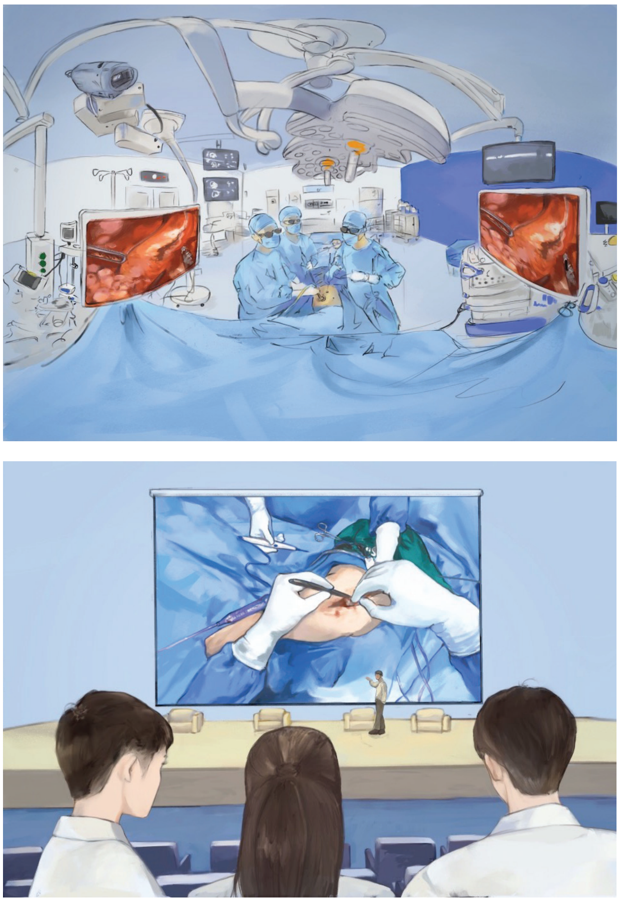

Figure 2. Broadcast of surgery in the metaverse

patients' medical data and imaging to help guide surgeons during procedures, particularly in minimally invasive and robotic surgeries. However, minimally invasive and robotic surgery have several issues regarding limited maneuverability and surgical view.[33] These systems can help identify landmarks and structures, especially in oncology, for selective resection and organ-sparing surgeries.[34] A study showcased these guiding capabilities in urology.[35] The advancement of robot-assisted kidney transplantation has shown several benefits over conventional open kidney transplant procedures; however, identifying atheromatous plaques can be challenging, with surgeons unable to manually palpate potential plaque in the iliac vessels.[36] A virtual 3D model is obtained from a computed tomography scan imaging and then superimposed in real-time on the actual iliac vessels of the patients. van Leeuwen and van der Hage[37] showed several concepts that the metaverse could help to advance minimally invasive and robotic surgery, including: (1) high-fidelity procedural planning based on preoperative 3D imaging roadmaps, (2) the superimposition of live data and 3D imagery on endoscopic views (e.g., mixed reality visualizations and GPS-like navigation strategies), (3) dynamic lesion/tissue characterization via intraoperative imaging (e.g., drop-in ultrasound for in-depth detection) or fluorescence imaging (superficial detection), and (4) the use of machine learning strategies to alleviate the mounting cognitive input, to advance the interpretation of the surgical data output, and to guide image-to-patient registration. While integrating these concepts presents considerable challenges, the development and standalone use of each key concept can still be helpful.

Metaverse can also improve neurorehabilitation. Currently, VR systems have been used in the rehabilitation of various conditions, including stroke, Parkinson's disease, Alzheimer's disease, and brain injury, and in delaying cognitive decline.[38] The resulting neurological deficits caused by these conditions often require a long period- and resource-consuming rehabilitation. Findings on improving cognitive function after interaction with virtual realities help cement its potential use in neurorehabilitation. A safe, repetitive, and controlled environment can be tailored to each individual's needs, especially those with differences in cognitive function. Although the digitization and virtualization of cognitive function assessment and rehabilitation tools are routinely practiced, the metaverse offers cognitive function assessment and training in real-life activities. Patients can engage in virtual simulations to assess their ability to perform daily tasks, such as driving, shopping, and cooking, without any real-life consequences of any mistakes. Studies have shown improvements in several cognitive attributes associated with the frontal lobe, such as activities related to the immediate recall of memory and time- and event-based tasks. These improvements are associated with neuronal plasticity. Their fun and engaging nature also motivate patients to continue participating in each session. In motor function rehabilitation, highly interactive virtual realities strongly promote the activation and stimulation of the visual, proprioceptive, and vestibular regions of the brain, showing a significant increase in brain volume and activity levels in the VR-rehabilitated groups. It has been used to increase the active range of motion of the upper limbs and improve gait rehabilitation. While current advancements in gait rehabilitation rely on the use of treadmills with robot support to help gait and posture, the addition of VR devices can improve the patient's mood, perception of physical well-being, global cognitive functions, executive functions (such as perseveration, planning, and classification), cognitive flexibility, and selective attention. These findings regarding the effects of VR in neurobiology have been extensively discussed by Georgiev et al.[39]

Metaverse has also been used in the field of mental health. Virtual simulations may enhance aversion therapy, in which patients interact with objects or situations that cause anxiety and discomfort. Repeated exposure to the cause of anxiety helps increase the anxiety threshold and improve insensitivity to help alleviate anxiety and discomfort.[40] Metaverse can simulate various phobias, including fear of height, fear of insects, and even fear of flight. In addition, it provides patient monitoring, enabling the simulation to be stopped instantly when a patient is overwhelmed, thereby preventing full-blown anxiety and panic attacks. For soldiers with post-traumatic stress disorder, a simulated battle situation can mimic the triggers of their condition. This can also be applied to patients with agoraphobia or the fear of crowds. Patients who fear of social interaction can also benefit from the fact that people can freely interact in the metaverse. Metaverse can also be used in distraction therapy to alleviate pain and stress, allowing patients to shift their focus away from pain.[41] A study has shown the use of VR in assisting meditation and mindfulness sessions, significantly reducing sadness, anger, and anxiety and increasing relaxation.[40] Moreover, the metaverse allows patients with chronic conditions and long-term hospital stay to "get out" of the hospital and enjoy a change of scene, which could reduce their stress and shorten their hospital stays.[42]

Reality of metaverse

With sizeable investments made by numerous companies to enter the metaverse, the hype garnered from various fields, including medical education, should come as no surprise. Some ways in which the metaverse and its two key components in VR/AR have been adopted also help fuel the excitement behind the continuing development and implementation of this virtual world. As we look beneath its promises, several questions must be addressed before committing to its implementation. First, it is important to address its ability to achieve better outcomes than those of the traditional alternatives. A study in anatomy learning has shown conflicting reports on the use of the metaverse and traditional approach, with some showing better outcomes in VR- or AR-based learning, while others found no significant differences.[4] However, this study was conducted relatively short, which might show a slightly skewed result due to the initial excitement of trying a novel learning method and the perception of it being a more fun and enjoyable experience. More detailed studies over longer periods are necessary. After successfully establishing its effectiveness, further studies on its optimal role in medical education are required. Is it feasible to outright replace the need for a cadaver laboratory in favor of a "virtual" anatomy lab? If it can only be used as a complement to traditional methods, how should we best allocate time between these modalities? Which one provides better outcomes: a curriculum with more time allocation in metaverse-based learning or classical methods, or would it be better to make the time allocation equal? What about subjects other than anatomy?

In medical training, answers to these questions are straightforward. The inherent haptic nature of medical procedures will always require at least some training on real patients. Regardless of how immersive and high-fidelity the metaverse is programmed, trainees can never quite grasp the necessary force required for optimal chest compressions or the interaction between various surgical instruments and living tissues solely by training in the metaverse. Metaverse-based training is an introduction to basic and advanced procedures that helps trainees learn the core skills needed before performing them on patients. It provides a unique combination of immersive, repeatable, safe, programmable, and relatively cost-effective simulation. The goal is to determine the best way to incorporate these VR/AR simulations by analyzing the optimal amount of virtual simulation training before moving to in-person training using mannequins or performing it in dry laboratory environments.

Then arise questions on the costs of metaverse implementation. However, the general use of VR/AR devices can cost thousands of dollars for a single device. Relatively affordable VR headsets such as Oculus Quest 2 costs approximately $300, excluding the necessary personal computer system required to run the software, pushing the cost to more than a thousand dollars per system. Microsoft HoloLens, regarded as one of the more advanced AR systems, costs $3,500. Regarding the software, the prices of ready-for-purchase third-party educational programs range from free of charge to hundreds of dollars, depending on the hardware utilized, with varying levels of detail and fidelity reflecting their prices. Developing custom-made software tailored to higher institution curriculum costs and setting up these devices for a large number of students should be performed simultaneously to reduce significant investments further. Virtual simulation systems used in medical training commonly include both software and hardware because of the need for special instruments depending on the simulated procedure. While customized VR systems used in surgical training do not need to be purchased for regular VR/AR devices, they can cost up to 6-figure expenses for a single system. Additionally, the potential lifespan of VR/AR systems should also be considered. With the rapid development of both hardware and software in the metaverse, it may only take a relatively short time before the software outdates the hardware, rendering it obsolete.

Cost-benefit analysis studies regarding its use in medical education and training are still scarce. A study examining the cost-utility ratio between virtual and mannequin-based simulations for nursing students showed that virtual-based simulations cost a third as much as mannequin-based simulations, although the study was conducted with a limited number of participants (n = 48) over one simulation course.[43] While this may be the case, early investments to set up the system can still prove costly. Will it be worthwhile for institutions with established traditional learning methods to implement metaverse-based learning modalities? Or will it be more beneficial for relatively new institutions without established traditional learning facilities? Ultimately, the analyses will differ for each institution depending on their needs and planned implementation. The faculty members must determine whether a significant investment is justified. Concerns regarding motion sickness and visual fatigue after long periods of VR/AR use are well-documented.[44] Although VR/AR systems have been used for some time, there has yet to be a definitive solution to this problem. VR/AR might also lead to oversimplification of training tasks, leading trainees to adopt habits detrimental to performance.[45] Thus, for now, metaverse-based learning seems best suited to facilitate and complement existing education and training modalities instead of replacing them.

In conclusion, introducing the metaverse could revolutionize medical education and training. The potential virtualization of knowledge transfer and skill acquisition in a programmable world is a possibility only the metaverse can offer. Early adoption of the metaverse, including its components VR and AR, has shown promise that warrants excitement. However, several concerns must be addressed before implementation in medical education. As the building blocks of its implementation continue to develop, it is perhaps best to slowly integrate metaverse-based learning to enhance learning and training modalities further because the technology, regardless of its continuous advancement, will never fully replace the traditional ones.

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