Annals of Emerging Technologies in Computing (AETiC)
Vol. 9, No. 3, 2025

Review Article

A Systematic Literature Review on Virtual Reality Applications in Medical Education

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Received: 27th May 2025; Accepted: 30th June 2025; Published: 1st July 2025

Abstract: Virtual Reality is increasingly used in medical education, allowing students to experience clinical scenarios safely. This immersive approach holds significant potential for improving knowledge retention, procedural competence, and decision-making skills. This study critically analyses key VR technologies and their applications in medical training, focusing on identifying scalable and context-appropriate solutions for resource-limited settings. The goal is to provide actionable insights for African researchers, educators, and policymakers on how VR can be adapted and integrated into local medical education systems. A systematised literature review was conducted, and PubMed, Google Scholar, Scopus, and Science Direct were searched for studies on VR in medical education. The search used the keywords "VR" combined with "Medical Education." Studies unrelated to healthcare were excluded. Additionally, a custom web-mining algorithm identified VR technologies from companies, academia, and research organisations. Fifty papers and 30 VR technologies met the selection criteria. Several platforms, including Goggleminds, Immersion, Avantis, and HoloLens, were identified as having been customised for medical training. Universities have adopted these platforms to establish VR labs, enhancing medical education. Findings indicate that VR is realistic, feasible, impactful, and applicable, supporting technical and non-technical skill training. Beyond education, VR is also used in digital diagnostics, virtual therapy, surgery planning, patient care, and treatment management. VR is an emerging technology revolutionising medical education by enabling interactive learning and safer clinical training. It improves healthcare workers' performance and enhances patient safety. However, successful VR adoption depends on more than just technology. Policymakers must ensure equitable access to ICT infrastructure, develop supportive policies, and promote research and innovation in VR applications for healthcare.

Keywords: ***Augmented Reality; Healthcare; Medical Education; Virtual Reality***

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1. Introduction

1.1. Medical Education in Africa

Africa carries 25% of the world's disease burden [1]. However, it has only 3% of the doctors, produces less than 2% of all medications consumed on the continent, and spends only 1% of the global healthcare budget [1]. The goal of primary healthcare, focusing on prevention rather than treatment, subscribed to at Alma-Ata in 1978, is often ignored. Moreover, many of the African medical schools continue to train physicians and nurses who can only work in urban areas, ignoring most of the Africans who still live in rural areas [2].

It is reported that many medical schools in Africa continue to train medical students using traditional conventional approaches, including the use of cadavers and mannequins [3]. However, these approaches have several limitations, such as the need for the physical presence of students, which is not convenient in resource-constrained settings; the need for experts to train the students, who are also few in Africa; and the difficulty of helping to explain complex medical concepts using this approach [4].

William Wasswa and Jonathan Andrew Ware, "A Systematic Literature Review on Virtual Reality Applications in Medical Education", *Annals of Emerging Technologies in Computing (AETiC)*, Print ISSN: 2516-0281, Online ISSN: 2516-029X, pp. 50-68, Vol. 9, No. 3, 1st July 2025, Published by International Association for Educators and Researchers (IAER), DOI: 10.33166/AETiC.2025.03.004, Available: http://aetic.theiaer.org/archive/v9/v9n3/p4.html.

Currently, many medical students in Africa principally learn in the classroom throughout their pre-clinical years without real-life exposure; not until clinical rotations do they have exposure to real-world challenges. This can lead to a lack of practical skills when encountering clinical challenges. Furthermore, Africa's limited number of health experts makes medical training difficult. For example, Uganda has fewer than 30 pathologists and only 40 ophthalmologists; hence, offering practical training to students is always challenging [5].

Other factors affecting African medical education include outdated curricula, language barriers, and public health challenges. Emerging technologies like Virtual Reality (VR) have been developed and deployed in developed economies and have been proven to ameliorate these challenges [6]. Hence, this paper presents a literature review on VR applications in medical education.

The study was undertaken to provide African countries and other key stakeholders with information about VR technologies that can be adapted to their different contexts as they strengthen their medical education. This approach is meant to catalyse leap-frogging Africa's traditional medical education approaches and proactively leverage and mainstream VR in medical education.

1.2. Virtual Reality

Virtual Reality, not to be confused with Augmented Reality (AR), is the use of software to create an immersive simulated environment [6]. VR combines video and audio, which is then viewed via a headset, filling a person's field of view and creating the illusion of being in the generated environment. Over the years, different VR technologies have been developed, and these can be broadly classified into three levels.

(i) Fully immersive VR that completely immerses the user inside the computer-generated world, giving the user the impression that they are inside the synthetic world [7]. This is achieved using HMDs or multiple projections.

(ii) Semi-immersive VR that allows the user to have a virtual experience while connecting to the physical surroundings [8]. This can be achieved using tools like VR glasses and virtual theatres.

(iii) The non-immersive VR that gives a virtual experience through a computer where the user can control some characters or activities within the software, but the environment does not directly interact with the user [9]. An example of non-immersive VR is a desktop VR computer.

Figure 1 shows the VR system's five key components. In general, VR systems typically consist of a hardware platform (such as head-mounted displays and controllers), software applications, sensory input devices, feedback output devices, and a user interface that enables interaction with the virtual environment.

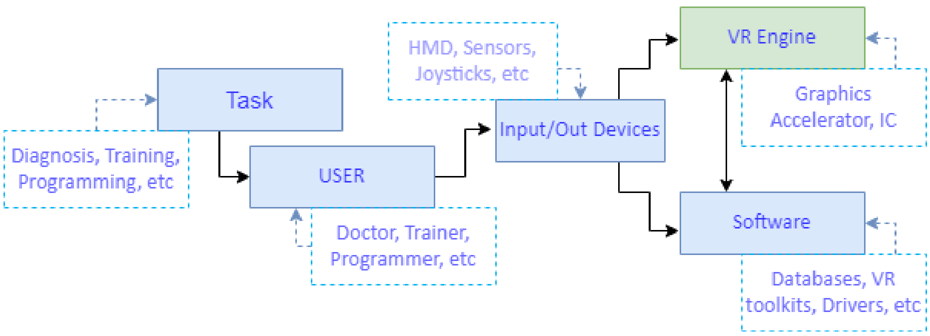

Figure 1. Components of a typical VR system

Task: The task refers to the specific activities users aim to achieve within the virtual environment. The task in a medical VR application might involve performing virtual surgeries or practising diagnostic procedures. The use of VR has been favoured in virtual surgeries due to many reasons, including a lack of mentors, a reduction in training hours, and issues concerning operative procedures, as shown in [8-10].

User: The user encompasses the individuals interacting with the VR system. Understanding user characteristics, preferences, and requirements is crucial for designing a VR experience that caters to the intended audience's needs. In VR for medical education, the users can be medical students, instructors, clinicians, or patients [11].

Input/output (I/O) Devices: The I/O devices are the hardware interfaces that enable users to input commands into the VR system. Input devices include handheld controllers, while the output devices include Head-Mounted Displays (HMD) like the *Oculus Rift* [12].

VR Engine: The VR engine, or the rendering engine, is the core software responsible for creating and rendering the virtual environment. It handles the processing of graphics, physics, mathematics, and interactions, ensuring a seamless and responsive experience. Examples of VR engines include *Unity3D* and *Unreal Engine*.

Software: Software encompasses the applications, simulations, and experiences users engage in in the virtual environment. Examples of software include the actual VR application, like Mediverse Medical education software, developed to offer the required experience to the users.

1.3. Virtual Reality in Healthcare and Medical Education

VR technology can address principal challenges like the limited number of experts and lack of access to physical 3D models to support the medical training challenges faced in Africa's medical education [13]. It has been reported that adopting VR for medical training in developing countries could be faster than in developed economies. This is attributed to the many opportunities for VR in Africa’s medical education [14]. VR can support medical education in Africa, achieve greater globalisation, and improve access to self-paced training for medical students [15]. Furthermore, VR can offer learners a platform to experience and master clinical scenarios without endangering the patients. When VR technologies are implemented effectively in medical education, they can enable engaging learning activities and interactive simulations. VR presents several use cases in medical education, including offering a way to enhance and improve the accessibility of learning materials [16], promoting scientific literacy [17], improving students’ attitudes toward pursuing medical training, and allowing learners to both view and manipulate virtual objects in a manner like the natural environment.

The VR has been reported to be a feasible teaching strategy to improve knowledge acquisition when used to supplement, but not replace, conventional teaching methods [18]. It has been reported to increase attention, enhance skills and confidence, influence users’ emotional responses to learning, and improve learning motivation. Furthermore, other outcomes, such as student satisfaction, self-efficacy, and engagement, have been reported to increase when using VR, making it an ideal viable tool in medical education in Africa [18]. However, the implementation of VR presents several challenges, including high costs, technical barriers, difficulty in content creation, and issues with data privacy and security [19-20]. The key to the successful implementation of VR in Africa is identifying these barriers and finding strategies to address them. Hence, this study critically analyses key VR technologies and their applications in medical training, with a focus on identifying scalable and context-appropriate solutions for resource-limited settings. The goal is to provide actionable insights for African researchers, educators, and policymakers on how VR can be adapted and integrated into local medical education systems.

2. Materials and Methods

2.1. Scientific databases literature search

This literature review followed the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and rigor in reporting. The objective was to identify and analyze studies focusing on the development, piloting, or evaluation of VR technologies in medical education. A comprehensive literature search was conducted across four scientific databases: PubMed, Google Scholar, Science Direct, and Scopus. The search was limited to studies published between January 2010 and January 2024. The search query included the following terms and Boolean operators: (“virtual reality” OR “VR”) AND (“medical education”). Search was tailored to each database where necessary, and additional articles were identified through reference list screening. Studies were included if they met the following criteria: (i) published in English between 2010 and 2024, (ii) published in peer-reviewed journals, (iii) focused on the development, piloting, or evaluation of VR technologies in medical education; and (iv) reported empirical findings or detailed case studies involving VR interventions. Studies not related to VR in medical education, reviews, editorials, opinion pieces, and conference abstracts without full text, and studies where VR applications focused solely on non-medical domains, e.g., gaming, were excluded.

To ensure methodological rigor, the quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT), version 2018. This tool was selected because it allows for the appraisal of qualitative, quantitative, and mixed-methods studies, which matched the diversity of methodologies among the included articles in the study. Two independent reviewers assessed each study across five relevant criteria in MMAT based on its methodological type (qualitative vs quantitative vs mixed-methods). Discrepancies were resolved through discussion and consensus.

A total of 50 studies met the inclusion criteria and were included in the final analysis. Data regarding study design, VR application, target population, outcomes, and context were extracted. A qualitative content analysis approach was used to categorize the themes, applications, and impact of VR in medical training. The study selection process is summarized in a PRISMA flow diagram in Figure 2.

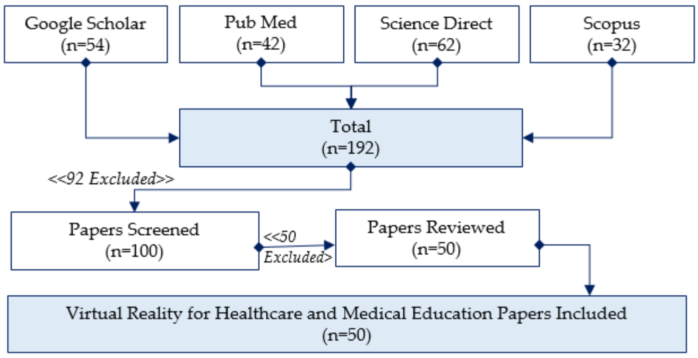

Figure 2. PRISMA flow chart for the VR evaluation papers literature search

2.2. Web search using a web-content mining algorithm

In addition to database searches, a custom web-content mining approach was employed to identify VR technologies and innovations related to medical education. This component of the study focused on publicly available data published by corporate companies, academic institutions, and research organizations. The search targeted gray literature such as official product websites, project repositories, digital health directories, company blogs, and news platforms. The mining process was conducted between August 2023 and January 2024 using a Python-based web scraping algorithm built with the BeautifulSoup and Selenium libraries. The tool automated the search for VR-related keywords (e.g., “virtual reality in medical education”, “VR healthcare simulation”, “VR clinical training tool”) across a predefined source (Google Search) as illustrated below.

FOR each keyword in the search list:
Construct Google search URL
Fetch search results page
Parse the HTML content of the page
FOR each search result:
Extract title, link, and description
IF description contains education or medical relevance:
Store keyword, title, link, and description
Store all collected entries in a CSV file.

Each retrieved item was evaluated for relevance by checking the following inclusion criteria:(i) the platform or technology must be explicitly designed for medical education, (ii) the tool must demonstrate real-world application, piloting, or deployment; and (iii) sufficient descriptive metadata (VR name/title, description, developer/owner, link) had to be available. Technologies aimed at entertainment, general education, or non-healthcare sectors were excluded. The initial search yielded over 100 VR platforms and tools, which were screened manually by two independent reviewers. Based on the predefined criteria, only 30 VR platforms were selected for deeper analysis and thematic classification in this review.

3. Results

The systematised review has identified educational VR platforms developed by companies as proprietary technologies, open education initiatives by higher academic institutions, and different researchers' evaluations of VR technologies in medical education, as discussed in the following sections.

3.1. Proprietary VR technologies

Several companies have developed VR technologies to support medical education. For example, Mediverse, developed by Gogglеminds, gives healthcare providers and medical schools access to on-demand simulation training anywhere. ClassVR [21] by Systems helps teachers to improve student engagement. Microsoft HoloLens [22] supports medical students and clinicians in using mixed reality to learn about the human body.

Immersion VR [23] by Immersion and VR Expedition by Robot Lab provide in-class virtual medical field trips to students without leaving the classrooms. *ARuVR* delivers engaging training, marketing, and collaborations safely and cost-effectively. *Eduverse* [24] by Avantis Education provides schools with a metaverse environment where students and teachers can interact through virtual classrooms.

PrismsVR leverages evidence-based pedagogical approaches and immersive, hands-on virtual environments to help students grasp core concepts in algebra and geometry. It enhances STEM education by integrating interactive modules, including those focused on biology, to support deeper conceptual understanding across scientific disciplines. The Gig immersive learning platform, by *GigXR*, provides access to a library of holographic applications specially focused on the healthcare industry. *BioDive* is a web-based VR experience built to teach students about marine biodiversity. *Floreo* offers VR-based social and life skills lessons for young people with autism spectrum disorder (ASD). *Holoeyes Edu* is specifically tailored to drive education and training for medical students and residents. *OssoVR* [25] by Osso VR Inc. is a surgical training platform for immersive and realistic experiences, *Touch Surgery* is an interactive surgical simulator with step-by-step guidance for various procedures.

Several VR platforms have been developed specifically for medical education, offering diverse applications across clinical training, anatomical visualization, and surgical simulation. For instance, EchoPixel [26] converts 2D medical imaging data into interactive 3D models, aiding in surgical planning and enhanced visualization.

In the field of anatomical education, 3D Organon VR Anatomy [27] allows users to explore detailed 3D models of the human body. Similarly, BodyViz [28] provides interactive 3D visualizations of medical imaging data, while Visible Body and Cyber-Anatomy MedVR support medical education through detailed and interactive anatomical content.

Therapeutic and clinical simulation platforms are also increasingly common. The VRHealth platform is used for pain management and rehabilitation, while SimX VR [29] supports practicing a wide range of clinical scenarios in a realistic virtual setting. Virti offers immersive simulations for medical training, and Prism Health Studio provides virtual simulations tailored for clinical skills training.

Surgical planning and simulation are supported by platforms such as Invivo Surgical, FundamentalVR [30], and VirtaMed [31], which offer high-fidelity, hands-on training for surgical procedures. ImmersiveTouch [32], Precision OS, Mentice [33], and 3D Systems Simbionix [34] provide VR-based training modules for various specialities, including orthopedic surgery, endovascular procedures, and other interventional practices.

Various VR platforms have been developed as powerful medical education tools. These platforms offer immersive experiences that simulate surgeries, anatomy exploration, and patient interactions. These platforms can significantly enhance medical training by providing realistic scenarios for students and practitioners. Replicating such VR applications in Africa holds tremendous potential to address challenges in medical education across the continent. African institutions can harness some of these platforms as shown in Table 1 to bridge educational gaps, offer hands-on training, and improve the overall quality of African medical education.

Table 1. VR Platforms for Medical Education

Platform	Manufacturer	Type of Immersion	User Group	Evidence of Effectiveness	Availability
Mediverse	*Goggleminds*	Fully immersive (VR HMD)	Medical students, healthcare professionals	Public evaluation; used in simulations	Commercial & Educational
ClassVR	Avantis system	Fully immersive (VR HMD)	K–12 education	Case studies and anecdotal reports from schools	Commercial

Microsoft HoloLens	Microsoft	Mixed Reality (MR)	Medical, engineering, military, education	Multiple peer-reviewed studies show educational benefits	Commercial
Immersion VR	Immersion VR	Fully immersive	General education, corporate training	General positive feedback, limited peer-reviewed studies	Commercial
VR Expedition 2.0	Robot Lab	360° video-based (Semi)	K–12 education	Classroom evaluations, improved engagement	Commercial (Edu license)
ARuVR	ARuVR	AR/VR/MR integrated	Enterprise training, healthcare	White papers and case studies, limited independent studies	Commercial
Eduverse	*Avantis Education*	Fully immersive	K–12, higher Education	Little public academic validation; promoted for virtual field trips	Commercial
Prisms	Reality	Fully immersive (VR HMD)	Middle/high school math students	Several pilot studies show learning gains in math	Commercial (Schools)
Gig Immersive Learning	*GigXR*	Fully immersive	Vocational and technical education	In-house case studies; limited peer-reviewed evidence	Commercial
Kai XR	*Kai*	360° video and VR	K–12 (focus on underserved groups)	Educator feedback; limited formal evaluation	Commercial (Edu)
Floreo VR	*Floreo*	Fully immersive (VR HMD)	Children with autism, special needs	Peer-reviewed clinical studies show improved social skills	Commercial (with clinical partners)
Holoeyes Edu	*Holoeyes Ed*	Mixed Reality (MR/AR)	Medical students and professionals	Case reports in surgical training; early positive outcomes	Commercial

3.2. VR for Education Initiatives

Over the last decade, several universities have established VR labs intending to strengthen medical education. For example, the Harvard Innovation Labs VR Studio [35] is an established lab with customized VR devices and educational software. Harvard Medical School employs VR through projects like HMS OPRS (Operating Room Patient Safety) for surgical training. Colorado State University has an education VR lab, and part of it is to supplement online human anatomy instruction [36]. The VR Opportunities at the University of Kansas uses VR experiences to help students with learning disabilities develop and practice social skills [37].

Universidad Católica San Antonio de Murcia built a VR platform to offer hands-on lessons about the coronavirus. At Purdue University, astronomy students use VR to explore interactive 3D models of astronomical objects in a virtual and collaborative environment. HoloAnatomy is a state-of-the-art medical education program developed at Case Western Reserve University that uses Microsoft HoloLens VR devices to enhance anatomy curricula among students [38]. Medical Simulation is a VR-based medical simulation platform that allows students to practice patient care scenarios. Imperial College of London's School of Medicine launched a remote VR-based clinical teaching program using Microsoft HoloLens to improve remote and distance learning during the COVID-19 pandemic. Besides enhancing medical education, VR has also been extensively used in academic institutions in the creation of virtual laboratories and supporting the performing of virtual high-level experiments for STEM education, for example, in the delivery of materials sciences [39], instruction of physics experimental training [40] and in delivering practical digital circuit design and electrical network analysis [41].

3.3. Evaluation of VR use cases in medical education

Globally, VR has shown great promise in enhancing medical education by providing students with immersive and interactive learning experiences [42]. It enables medical professionals and students to determine their level of competence for medical treatment before treating a patient. Many researchers have evaluated feasibility, applicability, perceptions, and acceptability in medical education as described below.

Ibrahim *et al.* [43] presented a scoping review of the role of immersive VR and augmented reality in medical communication. Most studies found these technologies helpful in improving medical communication, although user tolerability limitations were identified.

Nese *et al.* [44] presented a systematic literature review on VR and collaborative learning. Based on the literature review, the skills and competencies developed were divided into different categories.

Tobias *et al.* [45] assessed the feasibility of immersion, possible side effects, perceived stress, and didactic benefits of VR in medical emergency training. The participants perceived the degree of immersion and estimated learning success to be greater than the observers and proved to be more motivated post-training.

Noble *et al.* [46] investigated how combining spinal cord stimulation (SCS) with VR could offer a more effective approach to managing chronic pain. They suggest that using VR alongside SCS not only has the potential to enhance treatment outcomes but also brings economic advantages by improving long-term effectiveness.

Wong *et al.* [47] found that a 30-minute VR session helped women feel more relaxed during labor, focus on breathing, and distract themselves from pain. Thematic analysis showed these were key coping strategies. Overall, 70% said VR reduced pain, 60% felt less anxious, and 100% said they would recommend VR during labor.

Nagpal *et al.* [48] explored how VR can be used to manage chronic low back pain. Their review found that people enjoyed using VR and stuck with the programs, which is a big plus for treatment. They also discovered that patients using VR had lower stress hormone levels, suggesting it can help not just with pain but also with stress relief [48]. Other authors have evaluated the feasibility and acceptability of VR in pain management [49-51].

Real *et al.* [52] looked at how well an immersive VR program worked for training pediatric hematology clinicians on shared decision-making about hydroxyurea for sickle cell anemia. After going through the VR simulations, clinicians reported feeling much more confident in their communication skills across the board.

Buyego *et al.* [53] explored how VR could help frontline health workers in Uganda improve their handling of COVID-19 cases. They used VR simulations to train staff on bedside and ward-based care. Compared to traditional classroom training, those trained with VR learned faster, retained more information, and improved skills more effectively.

James *et al.* [54] carried out a scoping review of VR use in intensive care units. Their analysis showed that while VR in intensive care is still a new and developing field, it holds a lot of promise. Most applications are in the early stages, but the potential for VR to improve care in this setting is clear.

Ma *et al.* [55] evaluated the use of a VR platform, designed as a computer role-playing game, to enhance empathy in nursing students. Their study, using a 2 × 2 design (virtual vs. non-virtual), found that students who played the game in VR experienced higher levels of spatial presence and greater empathy than those using traditional methods.

Sapkaroski *et al.* [56] investigated whether VR or clinical role-play was more effective in improving clinical empathy during MRI scenarios. They assessed participants' ability to choose empathetic statements, and found that those trained with VR scored, on average, 5% higher than those who practiced through role-play. Other researchers have also assessed the role of VR in doctor-to-doctor communication [57-59]; and doctor-to-patient communication [60-62].

Bin *et al.* [63] introduced a VR tool for visualizing brain functions using functional MRI and diffusion tensor imaging (DTI). The application allows for immersive viewing of neural pathways and brain activity maps. Their evaluation showed that this tool has great potential for use in research, education, and even surgery planning.

Li *et al.* [64] conducted a meta-analysis to explore current trends and future possibilities of using VR for pain management. Their review offers an in-depth look at both clinical and experimental uses of VR in treating acute and chronic pain. The analysis found that VR significantly reduced pain perception in various conditions, with patients reporting improved pain relief and relaxation.

Tobias *et al.* [65] explored the possibility of using a wearable headset to live stream teaching ward rounds for medical students studying remotely. The students were highly impressed, with many strongly agreeing that the quality of both the session and the instructors was outstanding.

Huang *et al.* [66] created a collaborative virtual learning system for medical education. Their feasibility assessment revealed that the system offers an affordable, cross-platform solution that allows students and instructors to work together on tasks and participate in online group discussions.

Wright *et al.* [67] implemented a surgical VR platform to improve surgeon-patient alliance, patient satisfaction, and resident experience. Measures of the patient-physician partnership, trust, and understanding of their illness all increased.

Maresky *et al.* [68] tested and assessed computer-generated models' viability and efficacy in teaching cardiac anatomy. Compared to the control group, the students exposed to VR scored 21.4% higher in conventional content ($P = 0.004$), 26.4% higher in visual-spatial content ($P < 0.001$), and 23.9% higher overall ($P < 0.001$).

Bracq *et al.* [69] assessed the applicability of VR in healthcare professionals' nontechnical skills training. The authors noted that VR increased teamwork, communication, and situation awareness in nontechnical skills.

Nguyen *et al.* [70] evaluated the effectiveness of VRescuer, a VR application for disaster response training. The trainee can interfere in the rescue process by placing obstacles or adding more rescues along the way, which causes the rescue agent to reroute the paths. This was found to be a very effective training for disaster response.

Caroline *et al.* [71] described developing and evaluating a VR platform for teaching anatomy at the University of Dundee. The technology was found to be a valuable and acceptable mode of instruction.

Raphael *et al.* [72] developed a protocol for conducting navigation experiments in VR with physiological sensors using the EVE framework. The authors also describe a protocol that lists the steps for recruiting participants, attaching physiological sensors, administering the experiment using EVE, and assessing the collected data. A preliminary assessment of the platform showed it is feasible and usable [73].

Samadbeik *et al.* [74] investigated how VR is being used to train medical professionals. Of the 23 studies they reviewed, nearly half (48%) focused on laparoscopic surgery training, and in 74% of those cases, VR helped improve learning. The findings suggest that VR is a valuable tool for enhancing the performance of various medical groups.

Umoren *et al.* [75] developed an interactive virtual training platform for health professional learners to help them work effectively in clinical teams. This VR-based platform prepares learners to provide safe, high-quality care. As they progress through different scenarios, results showed that learners get better at choosing the right tools for each situation.

Dorozhkin *et al.* [76] created and tested a virtual Electrosurgical Skill Trainer for surgeons. When evaluating the tool, 33 out of 49 participants (67%) preferred using the virtual trainer over traditional methods like textbooks or animal models.

Real *et al.* [77] explored how residents viewed communication training using immersive VR. Most (92%) agreed that VR provided a realistic experience similar to real-life patient interactions, and 75% felt it was just as effective as working with standardized patients.

Sankaranarayanan *et al.* [78] created a new VR system, Gen2-VR, designed to train surgeons. A study testing its face and construct validity showed that Gen2-VR works effectively, addressing the limitations of existing head-mounted devices.

Grover *et al.* [79] validated a VR-based curriculum to teach key colonoscopy skills, including technical, cognitive, and integrative competencies. The results support incorporating VR simulations into a structured curriculum that combines instructional feedback with theoretical knowledge to enhance skill development in these areas.

Brewin *et al.* [80] assessed the face, content, and construct validity of a distributed simulation environment for training technical and non-technical endourology skills. The findings highlighted that simulation-based training is a valuable complement to traditional classroom learning.

Hudson *et al.* [81] evaluated how nurses used the Second Life VR platform to make decisions about insulin administration. They found that nurses with more years of experience had difficulty using the platform. However, they also noted that VR can effectively train and support clinical decision-making.

Wucherer *et al.* [82] used VR to evaluate surgical trainees' technical and cognitive skills. The results showed that training with VR helped surgeons complete tasks more quickly. The study emphasized the importance of developing realistic simulation environments to better prepare young residents for handling emergencies in the operating room.

Abelson *et al.* [83] explored the feasibility of creating a VR operating room to simulate a surgical crisis and assess its validity. The results showed that participants found the training environment realistic and had a positive view of the simulation.

Kaissar *et al.* [84] conducted a meta-analysis to assess the effectiveness of 3D visualization in teaching anatomy. The findings revealed that 3D visualization techniques are more effective than 2D methods in helping students acquire factual and spatial anatomy knowledge. Several other studies have evaluated the satisfaction levels of the use of VR in anatomy [85-89].

Rudarakanchana *et al.* [90] evaluated training in an immersive VR environment for endovascular repair of a ruptured abdominal aortic aneurysm. Participants rated the simulation highly, finding it helpful in developing technical (4/5) and communication skills (4/5). They also felt it was extremely valuable for improving teamwork (5/5) and patient safety (5/5).

Creutzfeldt *et al.* [91] used VR to evaluate situation awareness during cardiopulmonary resuscitation. Through a self-report tool, they discovered a significant improvement in situation awareness among medical students during team-based cardiopulmonary resuscitation training in a multiplayer virtual environment.

M. *et al.* [92] evaluated the feasibility, validity, and acceptability of centralized simulation-based training for healthcare professionals. The results showed that 90% of participants found the training models realistic and easy to use, 95% recommended using simulations in surgical training, and 95% approved of the faculty's teaching format for improving medical education.

Cohen *et al.* [93] explored the feasibility and reliability of skill assessments during a multi-agency, triple-site major incident response using VR. The study found that performance evaluations were practical and effective for experts and participants alike. Interestingly, non-technical skills tended to score higher than technical ones, highlighting the value of communication and decision-making in high-pressure situations.

The summary of some of the reviewed evaluation of VR in medical education is shown in Table 2.

Table 2. Evaluation of VR Medical Use Cases

Author (Year)	**VR Use Case**	**Evaluation Outcome**	**Study Design**	**Sample Size**	**Setting**	**Evaluation Method**	**Outcome Metric**
Ibrahim *et al.* [43]	Medical communication	Improved communication; tolerability issues	Scoping review	Multiple studies	Not specified	Review synthesis	Perceived improvement, limitations
Nese *et al.* [44]	Collaborative learning	Five categories of skills and competencies	Systematic literature review	Multiple studies	Various	Thematic synthesis	Categorization of skills
Tobias *et al.* [45]	Emergency training	Higher immersion and learning motivation	Experimental	Not specified	Medical training	Pre/post assessment	Immersion, motivation
Noble *et al.* [46]	Chronic pain + spinal cord stimulation	Improved treatment outcomes; economic benefits	Exploratory	Not specified	Chronic pain management	Theoretical analysis	Treatment efficacy, economic impact
Wong *et al.* [47]	Labor pain management	Reduced pain, anxiety; improved breathing	Qualitative + survey	Not specified	Labor ward	Thematic analysis, surveys	Pain, anxiety reduction
Nagpal *et al. [48]*	Chronic low back pain	High engagement, reduced stress	Review	Not specified	Pain management	Literature synthesis	Stress markers, adherence
Real *et al.* [52]	Training haematology clinicians	Increased communication confidence	Simulation study	Not specified	Paediatrics	Pre/post survey	Confidence in communication
Buyego *et al. [53]*	COVID-19 training in Uganda	Faster learning, better skill retention	Comparative	Not specified	Ugandan health facilities	Performance metrics	Learning speed, retention
James *et al.* [54]	Intensive care applications	Promising but early-stage	Scoping review	Multiple studies	ICU	Review	Development stage, potential
Ma *et al.* [55]	Nursing empathy training	Higher empathy and spatial presence	2x2 factorial	Not specified	Nursing school	Empathy and presence scores	Empathy, spatial presence

4. Discussion

The discussion interprets the findings of this review by moving beyond descriptive reporting presented in the results section to a structured and analytical synthesis of the findings. Drawing on Kirkpatrick’s model for evaluating training effectiveness, we explore the strengths of VR in medical education, examine the specific challenges faced in African contexts, consider policy and infrastructure implications, and assess the external validity and transferability of the findings to other low-resource settings.

4.1. Strengths of VR Implementation in Medical Education

This review reveals that VR has been increasingly employed across various domains of medical education, including anatomical and physiological visualisation, surgical simulation, mental health therapy, clinical decision-making, and soft skills development. Beyond descriptive enumeration, the effectiveness of these applications can be more rigorously understood using Kirkpatrick's model for evaluating training effectiveness, which assesses four levels: reaction, learning, behaviour, and results.

Across the literature, Level 1 (Reaction), learners' satisfaction and engagement were consistently high, with several studies reporting positive attitudes towards VR tools due to their immersive and interactive nature [45, 49, 85]. Evidence of Level 2 (Learning) outcomes, such as knowledge acquisition and procedural understanding, was widespread, particularly in anatomy training, surgical simulations, and diagnostic scenarios [63, 74, 85–89]. More importantly, several studies demonstrated Level 3 (Behaviour) outcomes, where learners translated VR-based knowledge into practical clinical tasks, enhancing communication and procedural confidence [57, 77, 87]. However, there remains limited evidence for Level 4 (Results) on the long-term impacts on patient outcomes or healthcare systems, especially in African contexts, as most of these studies stopped at evaluating the technology with the users (learners). This suggests a need for more longitudinal studies that connect VR medical training with real-world healthcare improvements.

In resource-constrained settings, VR has also demonstrated potential to enhance inclusivity, lower training costs, and overcome infrastructural bottlenecks, offering a scalable alternative to traditional methods that rely on cadavers, live patients, or expensive simulation centres [94–98]. This democratizing effect is particularly relevant to African countries, where physical infrastructure remains sparse, but mobile and digital technologies are increasingly accessible.

4.2. Challenges and Limitations in African Contexts

Despite the promising applications of VR in medical education, several challenges hinder its widespread adoption across African settings. A primary barrier is cost, including high initial investment in hardware, maintenance, and software licensing, which remains prohibitive for most institutions [45, 49, 77]. These costs are compounded by limited access to high-speed internet and reliable electricity, both of which are essential for immersive VR experiences but remain inconsistent across many parts of Africa [97, 98]. Technical infrastructure and skills gaps also pose significant limitations. Studies from this literature noted a lack of local technical expertise to manage, maintain, and adapt VR platforms to suit local curricula or healthcare needs [50, 77]. This dependency on external developers may reduce the sustainability of VR initiatives in African settings and limit opportunities for context-driven innovation.

Another challenge is data security and privacy, especially in clinical or patient simulation contexts. Some studies raised concerns about protecting sensitive data when VR is used in patient education [57, 60, 62]. Additionally, low digital literacy among learners and educators may restrict full utilization of VR's capabilities, as reported in several evaluations of user experience and adoption [49, 54, 77]. Crucially, while barriers such as cost and infrastructure are not unique to Africa, the compounded effect of systemic underinvestment, limited research and development capacity distinguishes the African experience from that of rural or underserved areas in high-income countries [97-98]. For instance, where rural hospitals in developed countries might face VR-related limitations, they often still operate within broader systems with stronger funding mechanisms and better technical support.

Furthermore, while the review identified VR's usefulness and acceptability [45, 49–54], few studies provided longitudinal evaluations, leaving a gap in evidence for long-term sustainability and impact. This highlights the need for more robust monitoring frameworks and follow-up studies to understand how VR interventions evolve in the African medical education setting. To overcome these challenges, studies such as [77, 98] recommend context-sensitive strategies including local co-development of content, capacity-building programs, and low-cost, mobile-based VR alternatives that reduce reliance on expensive headsets and high-end systems. However, these solutions were only briefly mentioned in the literature, and more empirical work is needed to test and scale such innovations.

4.3. Policy and Infrastructure Implications

The reviewed literature indicates that the successful implementation of VR in medical education is strongly tied to supportive policy frameworks and the development of enabling infrastructure. Several studies underscore VR's potential to reduce the dependency on physical infrastructure and traditional training equipment by providing cost-effective, scalable, and immersive alternatives [45, 49–54, 77–78]. This is particularly relevant in African contexts, where medical training institutions often operate with limited access to cadavers, labs, and specialized instructors [97, 98]. By adopting VR, education systems can overcome some of these systemic infrastructure deficits and extend access to quality training even in remote areas. However, the transition to VR-enhanced learning demands deliberate policy actions. These include integrating digital learning technologies into national health and education strategies, allocating dedicated funding streams, and establishing guidelines for evaluating, procuring, and maintaining VR systems [98]. Such policy support is crucial to ensure that VR does not remain a pilot initiative confined to a few donor-supported institutions but becomes a sustainable part of the broader educational ecosystem.

The results also highlight the need for investment in digital infrastructure, particularly in expanding internet connectivity, ensuring stable electricity, and promoting device accessibility in rural and underserved regions [97, 98]. Without these foundational elements, even the most promising VR applications risk underutilization or failure to scale. For example, studies that evaluated user experiences consistently emphasized the importance of technical readiness, including bandwidth capacity and hardware availability, as critical determinants of VR adoption and success [49, 77]. Additionally, institutional policies must address data governance, particularly as VR is increasingly used for doctor–patient communication, diagnostics, and therapy simulations [57, 60–62].

Regulatory frameworks should guide privacy, consent, and ethical use of VR technologies, especially when clinical scenarios involve sensitive patient information or decision-making simulations. Finally, some studies highlighted the growing importance of public–private partnerships and local innovation ecosystems in scaling VR adoption. For instance, platforms developed in collaboration with universities or startups showed greater alignment with local training needs and were more adaptable to contextual constraints [50, 77].

4.4. External Validity and Transferability of the Findings

Although this review adopts a global perspective, examining the use of VR in medical education across diverse geographic contexts, many of the findings are highly transferable to African settings. The challenges and enablers identified, such as limited digital infrastructure, high hardware and software costs, and the need for culturally and linguistically relevant content, are common to many low- and middle-income countries, including those in Africa. Lessons from successful VR implementations in Asia and Latin America may thus inform similar efforts on the African continent, provided that they are sensitively adapted to local educational systems, sociocultural contexts, and policy environments.

Many of the included studies were pilot projects or small-scale implementations lacking large sample sizes, long-term follow-up, or rigorous study designs such as randomized controlled trials. Furthermore, comparative evaluations across different settings were limited, making it difficult to draw strong conclusions about the effectiveness of specific approaches in varying healthcare or academic systems. As a result, while the findings offer valuable guidance for stakeholders in Africa, future research should prioritize context-specific validation, longitudinal impact assessment, and cross-regional comparisons to strengthen external validity and inform scalable, sustainable adoption of VR in medical education.

4.5. Limitations of the study

While this review provides a comprehensive overview of VR applications in medical education, several limitations must be acknowledged. These limitations pertain to the scope of included studies, methodological approaches, and the nature of reported outcomes. A significant proportion of the studies included in this review relied on self-reported data from participants, such as perceived confidence, satisfaction, and engagement levels. While these metrics offer valuable insight into user experience, they are inherently subjective and prone to several biases, including social desirability bias, recall bias, and confirmation bias. Self-reporting may not accurately reflect actual knowledge acquisition, skill proficiency, or long-term retention, which are critical in medical training. The studies reviewed varied widely in terms of design, sample size, intervention duration, content area, and evaluation metrics. This heterogeneity complicates cross-study comparisons and limits the ability to conduct a meta-analysis. Most studies assessed immediate or short-term outcomes following the VR experience. Few included follow-up evaluations to determine long-term retention of knowledge or skills, which is essential in medical education. There is no consensus on outcome measures or assessment tools used to evaluate the effectiveness of VR in medical education. This lack of standardization hinders meaningful comparisons and the development of evidence-based best practices.

5. Conclusion

This review has shown that VR has a lot of applications in health care education, and the assessment by different authors has shown that VR is realistic, feasible, favourable, impactful, and applicable in health care education. It has been shown that VR is instrumental in training and simulating technical and nontechnical skills like crisis management, self-awareness, communication skills, and teamwork. Besides being used for medical training, VR has been used in digital diagnostics, virtual therapy, surgery, patient care, fitness, and treatment planning. In addition to medical students, VR has been used in clinical settings.

This review highlighted that VR allows medical students to interact with the learning material more naturally, enables them to build a comprehensive and natural 'mental model' of the subject matter, allows them to explore, visualize, and minimize risks through virtual experiments instead of working with actual patients. Introducing VR in medical education will improve the performance of healthcare workers in a simulated environment and thus improve patient safety. It is, however, important to note that many elements beyond VR as a technology will determine its success in medical education. It is hence urged that policymakers create a favourable environment, like equity access to ICT facilities, and support innovation, research, development, and implementation of VR technologies in health care. The identified enablers for VR identified from this review include the development of customised curricula that fit the clinical workflow of the institution/nation, interdisciplinary collaborations including clinicians, engineers, computer scientists, and social workers; ethical considerations, infrastructure including ICT, buildings and electricity, training and capacity building, accessibility and inclusivity of the technology; and ensuring that administration and end users are engaged in the design and development of the VR programs.

It is important to note that specific regional and institutional contexts inform the findings and recommendations in this review. As such, generalizations should be made cautiously. The applicability and effectiveness of VR in medical education may vary across settings due to differences in infrastructure, resources, and educational frameworks. Future research should continue to evaluate VR implementations in diverse environments to ensure broader relevance and scalability.

CRediT Author Contribution Statement

Wasswa William: Data curation, Formal analysis, Investigation, Methodology, Resources, Writing—Original Draft and Writing—Review & Editing; Jonathan Andrew Ware: Conceptualization, Supervision, Review and Validation.

Conflict of interest

The authors declare no conflict of interest.

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