Exploring the Use of Metaverse in Future Medical Education: Navigating Adoption and Challenges

Anila Metaverse, Ghulam Farid, Faisal Ikram, Haleema Irfan, Shahila Jaleel, Umair Aziz, Muhammad Zahid Bashir, Imran A Siddiqui, Muhammad Ali, Ahmad Saqib, Shahzaib Zahid, Muhammad Suleman

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Anila Metaverse[1]; Ghulam Farid[2] PhD; Faisal Ikram[3] MBBS, FCPS; Haleema Irfan[4] MBBS, FCPS; Shahila Jaleel[5] MBBS, FCPS; Umair Aziz[6] MBBS; Muhammad Zahid Bashir[4] MBBS, FCPS; Imran A Siddiqui[7] MBBS; Muhammad Ali[4] MBBS; Ahmad Saqib[4] MBBS; Shahzaib Zahid[4] MBBS; Muhammad Suleman[4] MBBS

[1]Shalamar Medical & Dental College, Shalimar Link Road, Lahore Shalamar Medical & Dental College, Lahore Pakistan Lahore PK
[2]Shalimar Link Road Mughalpura Shalamar Medical & Dental College, Lahore Lahore PK
[3] Al- Faisal University, Saudi Arabia Saudi Arabia SA
[4]Shalimar Link Road, Lahore Shalamar Medical & Dental College Lahore PK
[5] Shaikh Khalifa Bin Zayed al- Nayan Medical and Dental College Lahore PK
[6]Shalamar Medical & Dental College, Shalimar Link Road, Lahore Shalamar Medical & Dental College Lahore PK
[7] TCU and UNTHSC School of Medicine, Fortworth, Texas, USA Fortworth, Texas, USA US

Corresponding Author:
Anila Metaverse
Shalamar Medical & Dental College, Shalimar Link Road, Lahore
Shalamar Medical & Dental College, Lahore Pakistan
Shalimar Link Road Mughalpura
Lahore
PK

Abstract

Background: The metaverse driven by immersive technologies such as virtual reality (VR), augmented reality (AR), mixed reality (MR), artificial intelligence (AI), and blockchain has begun to reshape medical education. By creating highly interactive and personalized learning environments, the metaverse offers promising opportunities to enhance experiential learning, foster collaboration, and overcome geographic and resource barriers.

Objective: This systematic review aimed to assess the current adoption and challenges of metaverse technologies in medical education.

Methods: Following PRISMA guidelines, six major databases were searched in November 2024 and updated in June 2025. Eligible studies were English-language publications from 2021 to 2025 investigating metaverse applications in medical and clinical education. Exclusion criteria were non-English studies, articles under two pages, book chapters and studies unrelated to medical education. After screening and quality assessment, 41 studies were included for qualitative synthesis.

Results: Evidence shows that the metaverse enhances experiential learning via simulated clinical environments, remote virtual dissections, AI-driven diagnostics, and collaborative global training. It expands accessibility, particularly for learners in underserved areas, by reducing geographic and financial barriers. However, significant challenges remain: high costs, limited infrastructure, privacy and data security concerns, digital literacy gaps, and resistance to adoption; especially in low and middle-income countries. Despite its promise, the metaverse cannot fully replace traditional hands-on clinical practice. Its successful integration into curricula depends on rigorous, evidence-based strategies and supportive policy frameworks.

Conclusions: The adoption of metaverse technologies represents a transformative shift in medical education. These simulations may enrich clinical skill training, encourage global collaboration, and support learner autonomy, mental well-being, and lifelong learning; particularly for students in remote or underserved areas. However, substantial challenges must be addressed, including privacy concerns, financial constraints, technological disparities, and ethical considerations. Realizing this potential requires evidence-based integration, ethical safeguards, inclusive strategies, and supportive policies that preserve the humanistic core of healthcare. Clinical Trial: N/A

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Keywords: Metaverse, Medical Education, Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), Immersive Learning, Experiential Learning, Healthcare Training, Digital

Literacy, Digital Privacy

INTRODUCTION

The metaverse is the convergence of physical and digital realities, enabled by advanced technologies such as virtual reality (VR), augmented reality (AR), mixed reality (MR), artificial intelligence (AI), and blockchain, and has rapidly evolved from a conceptual vision into an emerging ecosystem with transformative potential across many domains.[1] Initially driven by entertainment and gaming, the metaverse is now reshaping industries such as education, commerce, urban planning, and healthcare. Its defining features, including persistent 3D virtual worlds, immersive and interactive environments, and real-time global collaboration, offer unprecedented opportunities for experiential learning, skill development, and innovation.[2]

Metaverse platforms enable immersive practice, enhance engagement through gamification and personalized learning pathways, and bridge geographical and socioeconomic gaps by making world-class education accessible to learners worldwide. This is particularly promising in medical education, where experiential training, exposure to diverse cases, and real-time feedback are vital for skill acquisition and professional development. Virtual patient encounters, collaborative global simulations, and realistic operative practice can equip future healthcare professionals with greater confidence, competency, and empathy.[3] In education, especially medical education, the metaverse promises to revolutionize teaching and learning by enabling students to explore virtual anatomy labs, practice clinical scenarios, and conduct surgical simulations in safe and engaging environments.[4]

Despite these advantages, significant barriers hinder the widespread adoption of metaverse-based education in healthcare. Technological constraints, including the need for robust broadband, costly VR/AR hardware, and scalable IT infrastructure, pose major challenges for many institutions, especially those in under-resourced or rural areas.[5] Beyond hardware, there is a lack of established best practices and standardized guidelines for integrating these technologies into medical education curricula.[6] Concerns about data security, user privacy, and consent further compound the issue, particularly given the sensitivity of healthcare information.[7] Faculty may also resist these innovations due to unfamiliarity with the technology, skepticism about its efficacy, or difficulties in aligning virtual tools with traditional teaching methods.[8]

Additionally, virtual environments can contribute to cognitive overload, virtual fatigue, and inequities in access to technology, threatening student well-being and potentially diminishing educational outcomes. Without rigorous research to validate the effectiveness of metaverse tools, educators and regulators may hesitate to fully embrace these platforms. Patient safety concerns also persist; simulated practice must meet stringent educational and certification standards if it is to serve as a substitute for traditional hands-on learning. [9]

While the metaverse offers a bold and exciting vision for the future of medical education, enabling rich, accessible, and adaptable learning experiences; its successful integration will require a coordinated response to practical and ethical challenges. This includes investments in infrastructure, the development of robust guidelines and policies, faculty training, and careful attention to privacy, equity, and long-term evaluation of its educational impact. Addressing these barriers will help realize the metaverse's potential to advance healthcare training globally, ensuring that tomorrow's practitioners receive high-quality, immersive, and safe preparation for clinical practice. [10]

The aim of this review is to identify the core educational values of the metaverse, explore its practical uses in medical education, and highlight its adoption and the barriers to implementation. To the best of the researcher's knowledge, existing systematic literature reviews (SLRs) have discussed the use of the metaverse in medical education and covered its current status, benefits, and applications in teaching both medical students and teaching personnel; however, no study is available on the adoption of the metaverse and its challenges.[11] This review aims to inform educators, students, policymakers, and stakeholders about the strategic integration of metaverse technologies into future curricula and the associated barriers. It also proposes evidence-based guidelines to ensure the ethical, inclusive, and effective use of immersive technologies in medical training.

METHODOLOGY

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Information Sources

A comprehensive literature search was performed across six major databases between November 2024 and June 2025:PubMed (https://pubmed.ncbi.nlm.nih.gov),JMIR Publications (https://jmirpublications.com)IEEE Xplore (https://ieeexplore.ieee.org/Xplore/home.jsp),Google Scholar(https://scholar.google.com), Wiley Online Library (https://onlinelibrary.wiley.com), Wolters Kluwer (https://www.wolterskluwer.com/en)

Search Strategy

Search terms included variations and combinations of the following keywords and phrases:"Metaverse" OR "Virtual Reality" OR "VR" OR "Augmented Reality" OR "AR" OR "Mixed Reality" OR "Medical Education" OR "adoption" OR "Clinical education" OR "Simulation-Based Learning" OR "challenges" OR "Immersive Technology" OR "Healthcare Education" OR "Simulation Training" OR "Metaverse in Medical Education" OR "Metaverse in Healthcare Education"

Inclusion Criteria

Eligible studies were peer-reviewed articles published in English between January 2021 and June 2025 that investigated the application of metaverse technologies in medical or clinical education. Priority was given to research involving VR, AR, and AI-driven simulations, with additional consideration of studies addressing ethical implications, equity, and the digital divide.

Exclusion Criteria

Studies were excluded if they were non-English, less than two pages, book chapters, or outside the scope of medical education and training.

Data extraction and synthesis

A comprehensive search of six electronic databases; PubMed (n = 7,279), IEEE (n = 4,271), Wiley Online Library (n = 422), Wolters Kluwer (n = 298), JMIR (n = 212), and Google Scholar (n = 33); yielded 12,515 records. After removing duplicates, 9,286 unique records remained for title and abstract screening, of which 9,182 were excluded for not meeting the predefined inclusion criteria. The remaining 104 full-text articles were assessed for eligibility. Of these, 56 were excluded due to a lack of relevance to the research objectives, and a further 7 were excluded for reasons such as incomplete data or failure to meet methodological requirements. Ultimately, 41 studies met all inclusion criteria and were included in the final qualitative synthesis. Relevant data from these studies were systematically extracted and synthesized to address the aims of this review.

Screening reliability

Five independent reviewers (MA, MS, IS, SZ and SSJ) assessed abstracts to ensure the reliability of the screening process and avoid duplication. Any discrepant cases between the three were resolved by senior reviewers (UA, SJ, HI, and GF). Journal abstracts were downloaded, and screened in Rayyan. ai by using csv file$ formats Full text was also independently reviewed by (AJ, SJ, and GF) for all may be included, and disagreements were resolved through discussion with the lead reviewer (ZB, MIS, FI).

Comparative accuracy data was then extracted and synthesized from included studies by Authors (SA, FI, UA and GF) in Rayyan. ai tool. None of these were done with the help of automation tools. Any malcontent extracted data was addressed and solved via consensus between reviewers (IAS, ZB).

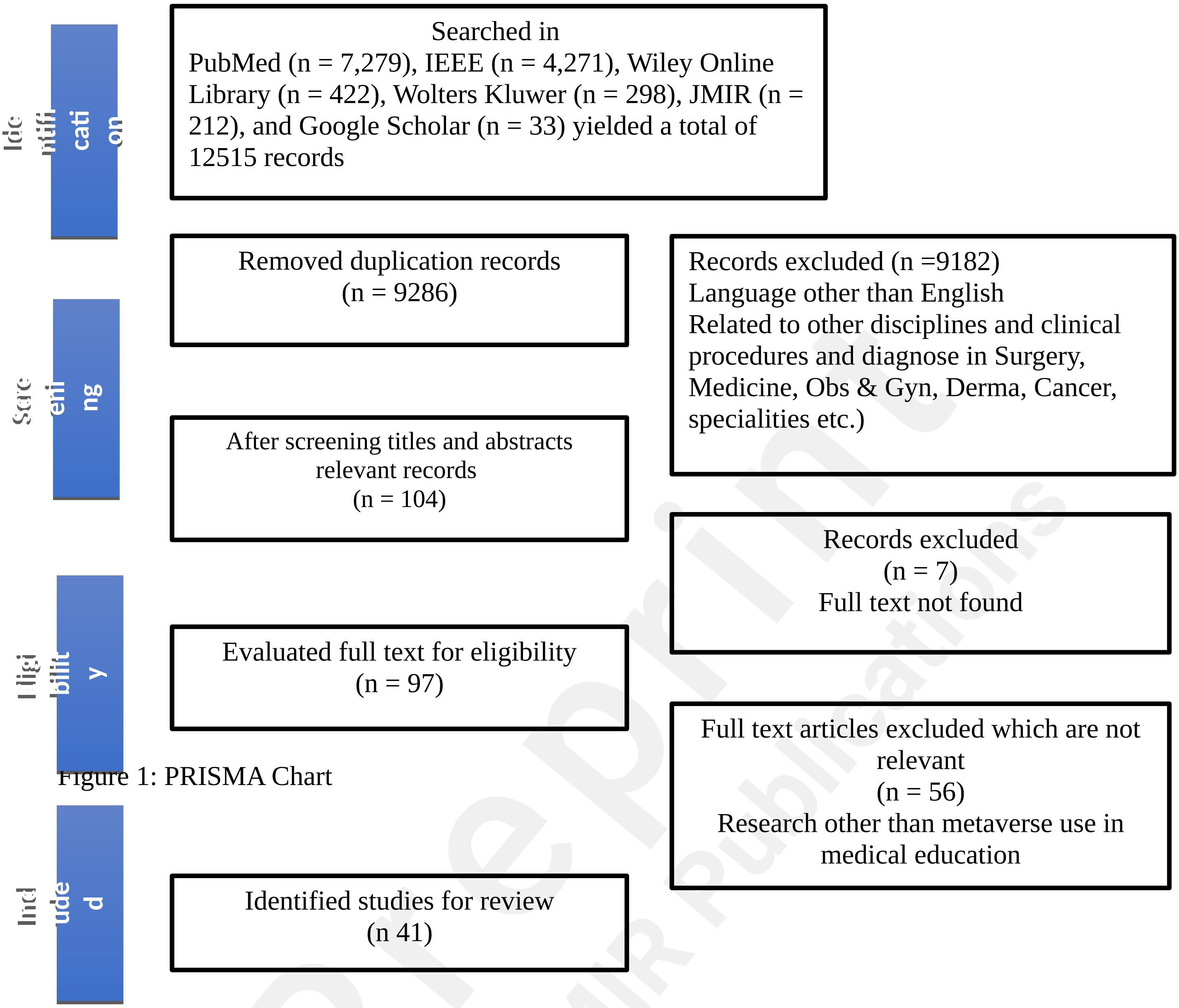

Figure 1: PRISMA Chart

RESULTS

The table 1 provides a synthesis of 41 recent studies examining the integration of metaverse technologies into medical education.

Author & Year	**Adoption of Metaverse in Medical Education**	**Barriers/Challenges**	**Conclusion**	**Study Type**
Li et al., 2025 [11]	Metaverse tools like AR/VR/MR are used across surgery training, anatomy teaching, and communication skills development, enhancing student engagement, confidence, and reducing training time.	Technical issues, hardware cost, varying implementation lengths, and limited standardization across programs.	Metaverse tech effectively supports medical teaching and skill improvement, warranting more curriculum integration.	Systematic review
Lau et al., 2025 [12]	Metaverse tools (AR/VR simulators) are used in acute-care training e.g., managing code blues, sepsis, stroke and to teach technical and nontechnical skills like teamwork and communication.	Technical difficulties, plus challenges in measuring educational impact compared to traditional high-fidelity simulation.	Metaverse is a growing educational tool with strengths and limitations; future research needed to compare it to other simulation modalities and guide curriculum planning.	Scoping review
Ghaempanah et al., 2024 [13]	The metaverse using AR/VR/AI/IoMT can enhance medical education via immersive training, skill development, virtual patient interaction, and better communication.	Limited internet access high cost of AR/VR gear, user discomfort, risk of overreliance on simulations, ethical/privacy concerns, lack of guidelines.	Metaverse offers promising support for clinical training but should supplement, not replace, traditional education. More guidelines and evidence are needed.	Narrative review
Arpaci et al., 2024 [14]	Metaverse platforms enable immersive, interactive, and personalized virtual education that supports autonomy and engagement in medical training.	Common method bias, sampling limitations, and limited transferability across different contexts.	Autonomy and hedonic motivation are key drivers of sustained metaverse adoption, implying practical considerations for educators and developers.	Cross-sectional
Chauhan et al., 2024 [15]	Interactive campaigns, gamified apps, virtual clinics, and collaborative simulations enhance skill-building and knowledge retention.	Equipment costs, data privacy, usability, accessibility, ethics, and lack of legislative support.	Strong interest in metaverse tools, but substantial technical and policy barriers must be tackled for mainstream adoption.	Survey-based study
Jin et al., 2024 [16]	The metaverse supports hybrid education and collaborative virtual learning spaces for medical instruction.	Digital inequality, social technophobia, and transparency concerns.	Trust and transparency drive metaverse adoption; digital access and cultural acceptance must be prioritized.	Empirical research
Kulkarni et al., 2024 [17]	Metaverse-based predictive models and digital twins enhance hands-on learning of complex procedures and diagnostics.	Gradient instability and implementation complexity in AI-driven predictive tools.	Metaverse-based predictive tools improve accuracy in simulated practice and encourage rapid skill acquisition.	Experimental

Letafati et al., 2024 [18]	Metaverse-driven healthcare education tools enable safe practice in virtual clinics and AI/ ML-based learning modules.	Privacy risks, data security, and vulnerability to cyberattacks.	Privacy-preserving measures and secure architectures must be adopted alongside metaverse tools for safe and ethical use.	Review article
Lewis et al., 2024 [19]	Immersive VR/AR tools enhance interactive learning and practical skill development in medical education.	Technological inequities, need for faculty adaptation, integration into existing curricula.	Metaverse tools can transform education if supported by proper infrastructure and pedagogical strategies.	Review
Mizuta et al., 2024 [20]	Metaverse-based programs promote student health and encourage physical activity in engaging virtual spaces.	Participant engagement issues, difficulty in standardizing program interventions.	Metaverse environments support increased participation and well-being if tailored to student needs.	Interventional Study
Ramos et al., 2024 [21]	Metaverse mental health interventions enhance access to support for tech-savvy and geographically diverse students.	Sociodemographic barriers, stigma, and preference differences across user groups.	Targeting specific groups can improve acceptance and impact of mental health interventions using metaverse tools.	Cross-sectional
Shwedeh et al., 2024 [22]	Metaverse adoption in higher education provides rich, collaborative, and borderless educational experiences.	Digital divides, inconsistent regulation, lack of institutional policy support.	Policymakers, educators, and stakeholders must collaborate to integrate metaverse successfully into curricula.	Empirical Investigation
Farrukh et al., 2024 [23]	Immersive simulations and remote training tools improve surgical skill acquisition and enhance practical education.	Privacy and data security risks, expensive setups, need for validation of simulations.	Metaverse holds substantial potential for hands-on skill training if validated and privacy-secured.	Narrative Review
Jagatheesaperumal et al., 2024 [24]	Metaverse provides interactive skill-training simulations and real-time collaborative learning.	Interoperability and integration issues across devices and platforms.	Metaverse could greatly enhance skill development with attention to standardization and interoperability.	Narrative Review
Rane et al., 2023 [25]	Virtual surgical training, 3D anatomy dissections, and collaborative simulations enhance practical skill sets.	Privacy concerns, interoperability with existing clinical tools, and regulatory compliance.	Metaverse-based surgical training can improve patient care preparedness if integrated securely and ethically.	Preprint
Suh et al., 2023 [26]	Metaverse-facilitated problem-based learning improves knowledge retention and diagnostic skill practice.	Lack of rigorous outcome data and the need for long-term sustainability research.	Interactive, virtual education enhances learning but cannot fully substitute hands-on clinical practice.	Peer-Reviewed
Kim & Kim et al., 2023 [27]	Mixed-reality and VR tools enable simulated surgical practice and urology skills training.	Limited clinical trials for wearable devices, discomfort, and acceptance challenges.	Extended-reality tools improve skills and accessibility, with further research needed to establish clinical benefits.	Review

Coşkun et al., 2023 [28]	Metaverse integration enhances e-health literacy and empowers adolescents with health knowledge.	Variability in adoption and sustainability of behavior change.	Metaverse tools support adolescent education if backed by institutional endorsement and evidence of long-term impacts.	Quantitative
Zaman., 2023 [29]	Metaverse provides accessible skill practice, virtual skill labs, and repeatable learning opportunities.	Digital inequity, lack of infrastructure, privacy risks, and platform accessibility.	Metaverse offers global healthcare training solutions if equity and privacy are prioritized.	Review
Prakash et al., 2023 [30]	Immersive tools and personalized simulations improve educational engagement and knowledge application.	Technical barriers, data security, faculty capacity-building.	Effective integration of metaverse requires clear goals and alignment with institutional priorities.	Literature Review
Imannezhad et al., 2023 [31]	Interactive 3D models and virtual flipped classrooms promote active and collaborative learning.	Device cost, addiction risks, mental health impacts.	Metaverse enhances education but cannot fully replace physical classrooms without proper guidelines.	Review
Shao et al., 2023 [32]	Extended-reality platforms provide experiential learning for clinical diagnostics and patient interactions.	Hardware and data privacy limitations, high setup costs.	Metaverse can improve practical training, though cost and privacy require attention.	Review/Conceptual
Alvarez-Risco et al., 2022 [33]	Interactive 3D training and collaborative virtual sessions enrich learning experiences.	Poor internet, variable institutional support.	Technical and institutional investments can overcome access and adoption barriers.	Multivariate (PLS-SEM)
Benrimoh et al., 2022 [34]	Immersive simulations improve medical training and remote therapeutic practices.	Privacy, mental health effects, need for regulation.	Metaverse-based therapies and simulations require rigorous ethical guidelines.	Commentary
Ganapathy., 2022 [35]	Virtual reality simulations enable hands-on skill practice in safe environments.	Demonstrating effectiveness, legal and privacy hurdles.	Metaverse can enhance education and care once legal and efficacy concerns are met.	Review
Gobeka et al., 2022 [36]	3D simulations improve surgical skill retention and visual-spatial understanding.	Technical and accessibility constraints.	Virtual simulations offer depth-perception benefits that enhance training.	Research study
Huynh et al., 2022 [37]	AI-driven tools provide rich learning experiences with interactive virtual patients.	Explainability of AI and interpretability of algorithms.	AI-metaverse synergy can elevate educational tools if transparency is ensured.	Survey/Review
Jeon et al., 2022 [38]	Virtual clinical training enhances safety and practice in nursing education.	Device variations, user trust, low immersion in some setups.	Metaverse expands opportunities for skill development if usability is improved.	Cross-sectional
Petrigna & Musumeci., 2022 [39]	Metaverse supports global anatomy learning and skill acquisition in collaborative environments.	Privacy, cybersecurity, internet access.	Virtual tools enhance global access to training if privacy and equity issues are managed.	Narrative Review

Weinberger., 2022 [40]	Metaverse allows immersive learning and collaborative research across disciplines.	Lack of a unified definition and conceptual understanding.	Metaverse holds great promise if its scope and concepts are clearly defined.	Literature Review
Skalidis et al., 2022 [41]	AR/VR tools enhance cardiovascular education and procedural training.	Infrastructure cost, privacy concerns, interoperability.	Metaverse can transform cardiovascular care and teaching if adopted responsibly.	Review Article
Kala., 2022 [42]	Metaverse simulations support personalized training and collaborative skill-building.	Integration complexity, privacy, and security concerns.	Virtual clinical training enhances learner experience with appropriate privacy protections.	Conceptual Paper
Pregowska et al., 2022 [43]	Mixed-reality tools help visualize complex structures and processes.	User accessibility and hardware limitations.	Interactive tools improve retention and engagement if they are accessible and affordable.	Descriptive
Bansal et al., 2022 [44]	Metaverse aids clinical teaching and telemedicine through simulated practice and real-time collaboration.	Technical and legal challenges including privacy, security, and interoperability.	Metaverse promises advanced healthcare training if legal and technical risks are mitigated.	Survey
Almarzouqi et al., 2022 [45]	Interactive virtual classrooms support personalized education and skill-sharing.	Response bias, cultural influences on adoption.	Ease of use and perceived usefulness promote adoption if cultural factors are considered.	Cross-sectional
Wang et al., 2022 [46]	Metaverse-powered diagnostic learning enhances student engagement and accuracy.	Privacy, data disparities, regulation hurdles.	Metaverse and AI improve scalability and effectiveness if supported by strong regulation.	Review/Conceptual
Lin et al., 2022 [47]	Metaverse supports personalized, visualized teaching and collaborative virtual practice.	Privacy/security concerns, ethical and governance gaps.	Metaverse can make learning more engaging and cost-effective if ethical and security frameworks are adopted.	Survey/Review
Yang et al., 2022 [48]	Metaverse tools enable surgical skill practice and AI-driven clinical learning.	AI opacity, lack of empathy, privacy and security.	Immersive technologies improve hospital education if transparency and privacy are ensured.	Review
Gurusamy & Mohamed., 2021 [49]	AI-assisted virtual simulations support clinical skill practice and enhance diagnostic accuracy.	Data privacy and acceptance concerns, technology costs.	AI and virtual tools improve healthcare training with careful attention to data governance and cost.	Review
Kye et al., 2021 [50]	Virtual consultations and AR-assisted teaching support practical skill learning.	Privacy and adaptation risks, social disconnection.	Metaverse can enrich practical education if mental health and privacy considerations are managed.	Review
Thomason., 2021 [51]	Interactive gamified learning supports collaborative education and skill mastery.	Security risks, implementation complexity, and scalability.	Metaverse holds significant potential to innovate collaborative training with proper security and implementation.	Narrative Review

Table 1: overview of the selected studies on adoption and challenges of metaverse technologies into medical education.

Overall, the findings in table 1, highlight that the metaverse is regarded as a transformative educational tool, offering immersive, interactive and highly personalized learning experiences that enhance both knowledge retention and skill acquisition. Commonly reported applications include virtual simulations, three-dimensional anatomy dissections, AI-assisted diagnostics and remote clinical skills training. The literature underscores the metaverse's potential to promote experiential learning, enable collaborative practice, and transcend geographic and institutional barriers, thereby expanding access to high-quality education.

Despite these promising outcomes, substantial challenges have also been noted. Technological limitations such as the high cost of equipment, unreliable internet access, and insufficient digital infrastructure were frequently cited, especially in low and middle-income countries. Ethical and legal considerations surrounding data privacy, cybersecurity, and the realism of virtual simulations also emerged as significant concerns. Furthermore, barriers including inadequate digital literacy, user resistance to new technologies, and insufficient faculty training may restrict the effective implementation of these tools within traditional curricula.

Nevertheless, a cautious optimism prevails across the reviewed literature. The majority of authors agree that the metaverse holds considerable potential to enhance medical education and healthcare delivery by improving accessibility, engagement, and the overall quality of training. However, most studies also stress that these tools cannot fully substitute for hands-on clinical practice. Researchers advocate a balanced, evidence-based approach to adoption, that is supported by appropriate regulatory frameworks, robust data protection policies, ongoing user support and long-term sustainability. Overall, the reviewed literature comprising empirical studies, cross-sectional research, narrative reviews and conceptual analyses reflects a diverse range of perspectives and emphasizes the need for further rigorous evaluation and continued innovation in this rapidly evolving field.

Adoption of Metaverse in Medical Education

Theme	Key Dimensions
Immersive Learning and Simulation	• Virtual anatomy and dissection labs enhance spatial and structural understanding. • Interactive case-based scenarios help improve diagnostic and management skills. • High-fidelity VR/AR learning immerses students in authentic clinical experiences. • Learners practice in real-time 3D clinical environments that replicate real-world settings. • Virtual practice improves diagnostic accuracy and decision-making.
Personalized and Adaptive Education	• AI algorithms personalize learning pathways for individual student progress. • Performance tracking systems identify strengths and areas needing improvement. • Adaptive testing formats adjust question difficulty based on learner performance. • Emotion-aware algorithms respond to student engagement and stress levels. • Customizable learning environments reflect students' preferences and needs.
Global Collaboration and Accessibility	• Multinational virtual classrooms connect learners across countries. • Students collaborate across time zones, broadening perspectives. • International teamwork enhances cultural awareness and global health education. • Inter-institutional platforms facilitate resource sharing and cooperative learning. • Rural and remote learners gain access to world-class educational content.
Skill Acquisition and Surgical Training	• Stepwise skill-building enhances surgical proficiency gradually. • Haptic VR devices simulate hands-on surgical practice. • Simulated complications prepare students for unexpected clinical events. • Virtual procedure walkthroughs improve retention of surgical steps. • Preoperative skill rehearsal builds student confidence before real surgery. • Operative task simulations improve surgical speed and accuracy. • Repeated virtual learning allows mastery of technical procedures.
Ethical, Privacy, and Data Security	• Data anonymization protocols protect sensitive information. • User access controls limit data visibility to authorized individuals. • End-to-end encryption secures communications and data exchange. • Consent management systems respect privacy rights and choices. • Privacy-preserving AI protects learner and patient identities. • Cybersecurity training raises awareness of potential digital threats. • Institutional ethical compliance aligns with professional standards. • Surveillance risk mitigation strategies maintain a safe digital environment.

Faculty Development and Institutional Readiness	• Faculty receive digital training to use metaverse tools effectively. • Change management strategies and address faculty resistance to innovation. • IT-pedagogy collaboration enhances curriculum design. • Institutions improve their technical infrastructure to support metaverse tools. • Curriculum alignment strategies integrate VR/AR seamlessly into programs. • Mentorship programs support immersive teaching skill development.
Technical Infrastructure and Integration	• Broadband and 5G internet enable seamless virtual learning experiences. • AR/VR devices interoperate across platforms and systems. • Learning management system integration centralizes student data and progress. • Low-bandwidth optimization supports diverse technological environments. • Cross-device functionality provides flexible access to content.
Digital Literacy and Student Readiness	• VR onboarding sessions introduce students to new tools. • Interface training enhances learners' comfort with virtual platforms. • Interpretation of feedback empowers students to use data for improvement. • Digital professionalism ethics encourage appropriate behavior online. • Tool-specific proficiency prepares students for diverse virtual learning systems.
Mental Health and Well-being	• Anonymous mental health chats encourage help-seeking behavior. • Mental health analytics identify students at risk of burnout. • Integration with institutional support bridges virtual and real-world care.
AI and Decision Support Integration	• AI-guided diagnostic cases enhance clinical reasoning. • Smart tutoring agents offer personalized learning support. • Adaptive AI assessments tailor questions to skill level. • Real-time coaching algorithms offer guidance during practice. • AI-assisted grading simplifies evaluation and improves consistency.
Cross-Discipline Learning	• Role-play across disciplines enhances communication and empathy. • Shared virtual patients improve cooperative clinical care. • Joint diagnostic projects foster collaborative problem-solving. • Communication training strengthens teamwork and patient safety. • Group problem-solving exercises simulate real-world practice. • Multidisciplinary rounds allow shared decision-making across professions. • Mutual skill exchange exercises highlight the value of each team member.
Evaluation and Competency Assessment	• Virtual OSCEs simulate clinical exams in a controlled environment. • Peer-based evaluations encourage constructive feedback. • AI feedback analytics identify performance gaps and strengths. • Formative self-assessments encourage continuous learning. • Real-time scoreboards motivate students to improve.
Cultural and Contextual Sensitivity	• Socioeconomic considerations ensure relevance to all contexts. • Community-based VR learning engages learners with local health challenges. • Religion- and ethics-integrated content acknowledges cultural values.

	• Healthcare models highlight local traditions and practices. • Language inclusion improves accessibility for multilingual learners. • Regional clinical scenarios reflect diverse practice settings.
Policy and Regulation	• Long-term funding models promote sustainable metaverse initiatives. • Public-private collaboration supports innovation in medical education. • Open educational resources increase content accessibility. • Environmental impact tracking promotes technological choices. • Institutional accreditation supports the recognition of VR-based learning. • Metaverse regulation ethics shape responsible technology use.

Table 2: Thematic Synthesis of Adoption of Metaverse in Medical Education

Immersive Learning and Simulation

A substantial number of studies identified immersive simulation as a core strength of metaverse-based education. Virtual anatomy labs and 3D dissection tools were shown to enhance spatial understanding and structural visualization [42,43]. These environments enabled students to interact with anatomical structures in lifelike detail, thereby improving engagement and knowledge retention. Interactive, case-based simulations helped learners refine diagnostic and clinical decision-making skills [32,49], while high-fidelity VR/AR tools immersed students in near-authentic clinical settings [19,23]. Real-time 3D practice environments, as reported in [13,21], allowed learners to apply theoretical knowledge in realistic scenarios, fostering critical thinking and building confidence. Additionally, metaverse-based diagnostic simulations improved accuracy and accelerated decision-making, particularly in disciplines such as surgery and internal medicine [11,24].

Personalized and Adaptive Education

Several studies highlighted the metaverse's capacity to support personalized learning through AI-powered tools. Adaptive technologies such as digital twins and predictive models were employed to tailor educational experiences to individual learner needs, thereby enhancing knowledge retention and engagement [17,42]. Performance tracking systems embedded within these platforms identified areas of strength and weakness, enabling data-driven self-improvement [18,46]. Emerging approaches, including emotion-aware algorithms and customizable learning environments, were also noted in studies emphasizing learner-centric design [14,45].

Global Collaboration and Accessibility

Metaverse platforms were reported to overcome geographical barriers, enabling international collaboration and cross-cultural exposure. Studies such as [22,33] described virtual classrooms that connected students across different time zones, fostering global health perspectives and teamwork. This accessibility was particularly valuable for learners in remote or underserved regions, who could now access high-quality medical content without the constraints of location [39,28]. Additionally, inter-institutional collaborations within these platforms facilitated shared learning and effective knowledge transfer [47].

Skill Acquisition and Surgical Training

Surgical education has emerged as one of the most active areas of metaverse adoption. Studies reported that repeated virtual practice significantly enhanced procedural retention and technical precision [11,36]. The use of haptic feedback devices enabled realistic surgical rehearsal, improving tactile learning [27]. Virtual simulations prepared students for potential intraoperative complications and allowed for preoperative rehearsals in a risk-free environment [35,48]. Furthermore, metaverse-based training was associated with increased confidence and faster skill acquisition [49,42].

Ethical, Privacy, and Data Security

As metaverse platforms handle sensitive learner and patient data, multiple studies emphasized the need for robust ethical safeguards. Privacy concerns and the risk of cyberattacks were among the most frequently cited barriers [18,34]. The use of secure data encryption and strict user access controls was highlighted as essential for maintaining trust [44,50]. Consent management systems and anonymization protocols were considered vital for upholding professional standards in digital learning environments [19,23]. Additionally, ethical compliance and strong institutional governance frameworks were recommended as prerequisites for safe and responsible adoption [48,47].

Faculty Development and Institutional Readiness

For successful metaverse integration, faculty support and institutional readiness were considered essential. Many studies reported that providing digital training for educators significantly influenced adoption success [19,42]. Effective change management strategies were necessary to reduce faculty resistance and ensure alignment with pedagogical goals [16,30]. Mentorship programs and collaborations between IT specialists and educators facilitated the effective integration of immersive tools into curricula [11,46]. Several authors also emphasized the importance of curriculum realignment to seamlessly incorporate metaverse-based modules [23,32].

Technical Infrastructure and Integration

Reliable technical infrastructure was identified as a prerequisite for smooth adoption. Studies highlighted the importance of robust internet connectivity and platform compatibility across devices [22,36]. Integrating Learning Management Systems (LMS) and optimizing platforms for low-bandwidth settings were also recommended to accommodate diverse user environments [33,50]. Ensuring cross-device functionality and consistent AR/VR performance across hardware systems was considered essential for scalability [42,20]. These infrastructural enablers were frequently associated with improved user experience and wider adoption.

Digital Literacy and Student Readiness

Adoption also depended on students' comfort and familiarity with virtual tools. Several studies identified onboarding sessions, interface training, and guidance on feedback interpretation as crucial for preparing learners [15,21]. Emotional readiness and digital professionalism were particularly emphasized in simulations involving ethical or patient-centered tasks [34,45]. Research indicated that digitally literate students were more likely to engage meaningfully with metaverse content, leading to improved learning outcomes [14,42].

Mental Health and Well-being

Although this theme was less frequently reported, a few studies examined the metaverse's potential to support mental well-being. Virtual platforms could provide anonymous mental health support and facilitate group-based interventions tailored to vulnerable populations [21]. These features were particularly valuable in contexts where stigma limits access to traditional care.

AI and Decision Support Integration

AI-powered metaverse tools were found to enhance decision-making, diagnostics, and personalized tutoring. Intelligent agents and real-time AI feedback improved learning accuracy and engagement [17, 46]. Digital twins and adaptive testing further customized clinical practice simulations to individual needs, creating dynamic and responsive learning environments [31, 32]. AI-enabled grading and diagnostics were regarded as efficient tools for monitoring progress and assessing competency [37, 49].

Cross-Discipline Learning

Metaverse platforms also facilitated interdisciplinary collaboration. Several studies highlighted the use of shared virtual patients and multidisciplinary teamwork simulations [40, 47]. These initiatives fostered a deeper understanding of professional roles and enhanced communication in clinical contexts [11, 51]. Interactive role-play and group problem-solving exercises within metaverse environments enabled students to collectively experience real-world challenges [41, 42].

Evaluation and Competency Assessment

Finally, evaluation systems within the metaverse were reported to offer innovative approaches for assessing clinical competency. Virtual OSCEs, peer evaluations, and AI-driven analytics enabled formative assessments and continuous feedback loops [42, 19]. Real-time scoring and adaptive assessments enhanced motivation and accountability, while aligning closely with established medical education standards [32, 42].

Cultural and Contextual Sensitivity

The metaverse represents a major step forward in the digital humanities. This integration opens new possibilities for presenting and preserving cultural heritage in this growing space. Addressing the challenge of portraying historical figures and cultures appropriately, close collaboration with cultural experts is required to ensure both accuracy and respect [66]. There is growing discussion about how the metaverse could influence religion and spiritual practices. For billions of people, faith is a central part of their social identity and a key pillar of emotional and psychological well-being. The metaverse could open up fresh opportunities to connect with these long-standing sources of meaning and human fulfillment in entirely new ways [67].

Policy and Regulation

The use of metaverse also raises important ethical concerns, such as the risk of losing personal identity [66]. Creating well-structured implementation strategies enables institutions and educators to maximize the advantages of emerging technologies while anticipating and managing potential challenges, ensuring a balanced and impactful learning experience for future healthcare professionals [68].

Barriers and Challenges in the Adoption of Metaverse in Medical Education (with Subtheme Statements)

Barrier Theme	Descriptive Statements
Technical and Infrastructure Limitations	• Many institutions lack access to high-speed internet necessary for metaverse applications. • There is a widespread shortage of AR/VR devices compatible with immersive technologies. • Interoperability issues persist between different hardware and software systems. • Current institutional hardware often cannot support high-performance simulations. • Maintaining and updating metaverse platforms requires significant ongoing investment. • Device variability among students leads to unequal access and usability.
Privacy, Ethics, and Data Security	• Data collected in virtual environments is often vulnerable to breaches and misuse. • Many platforms do not use end-to-end encryption or secure transmission protocols. • Consent management systems are underdeveloped or absent in virtual learning tools. • Institutions face challenges ensuring compliance with data protection regulations. • Storage and sharing of sensitive student performance data remain unsecured.
Faculty Readiness and Resistance	• There is limited availability of training programs on virtual teaching methods. • Institutions often fail to incentivize faculty to engage with digital platforms. • Many educators lack confidence in their ability to teach within metaverse environments. • Technophobia continues to be a barrier among senior faculty members. • Time constraints discourage faculty from exploring and integrating new tools. • Collaboration between educators and IT staff is insufficient for implementation. • Faculty often do not receive technical support tailored to educational innovation. • Recognition and evaluation systems do not reward digital teaching initiatives.
Cost and Resource Constraints	• The high cost of AR/VR technology poses a barrier to institutional adoption. • Funding for digital innovation in education remains limited or inconsistent. • Financial resources are often insufficient for maintenance and software upgrades.

	• Institutions struggle to budget for both conventional and metaverse education. • Students may be unable to afford necessary personal hardware. • Budget allocations often prioritize infrastructure over educational innovation. • Disparities in institutional funding create unequal access to immersive tools. • Content development for simulations requires substantial investment.
Regulatory and Policy Gaps	• There is a lack of national or institutional legal frameworks for metaverse use. • Accreditation bodies have not standardized criteria for virtual education platforms. • Institutional policies for immersive learning are inconsistent or missing entirely. • Policy changes are slow to adapt to the evolving technological landscape. • Intellectual property rights for virtual content are poorly defined. • Benchmarks for evaluating metaverse-based learning outcomes are underdeveloped.
Student Readiness and Acceptance	• Many learners lack prior exposure or training in virtual learning tools. • Virtual settings can induce anxiety or confusion in some students. • VR/AR environments can disorient students, especially during extended use. • Initial novelty can fade, leading to disengagement over time. • Students struggle with interface navigation without sufficient support. • Some learners are demotivated by the lack of physical presence or peer interaction.
Evaluation and Outcome Uncertainty	• There is insufficient empirical research on the effectiveness of metaverse education. • Many platforms lack accurate tools for performance assessment. • Learner progress tracking can be subjective or unreliable. • Inconsistency in data collection affects evaluation integrity. • Analytic tools may produce biased or incomplete feedback. • AI-generated assessments lack transparency and interpretability.
Integration in Existing Curriculum	• Metaverse tools often do not align with current learning objectives. • Faculty struggle to balance multiple educational technologies simultaneously. • Simulation tools may not synchronize with institutional LMS systems. • Scheduling metaverse sessions within rigid academic calendars is difficult. • Integration often lacks input from multidisciplinary teams. • Faculty may resist curriculum overhaul due to workload or uncertainty. • Integration demands substantial time and resources that are rarely allocated.
Mental Health and Wellbeing Risks	• Extended use of VR may cause fatigue and burnout among learners. • Motion sickness is a common side effect of immersive simulations. • Digital environments can lead to increased social isolation. • Some students may become overly dependent on virtual settings. • High-tech environments can trigger stress and performance anxiety. • Simulations may reduce empathy by distancing learners from real patients.

Table 3: Barriers and Challenges in Adopting the Metaverse in Medical Education

Interpretation of Barriers and Challenges in Adopting the Metaverse in Medical Education

As the metaverse gains traction in medical education, many studies highlight its promise yet they also bring to light a range of practical, ethical, and pedagogical challenges that must be addressed before widespread adoption becomes feasible. Here's how these barriers, organized into themes, appear across the literature:

Technical and Infrastructure Limitations

A recurring barrier identified across studies is the lack of adequate infrastructure to support metaverse technologies. For example, many institutions do not have the necessary hardware or internet bandwidth to run AR/VR simulations smoothly [11, 29]. Interoperability issues—where different devices or platforms fail to work seamlessly—further hinder the learning experience [24, 41]. Limited device accessibility can also widen the digital divide among students, especially in low-resource settings [36]. These challenges are compounded by the high costs of maintaining advanced platforms and the need for frequent updates [42].

Privacy, Ethics, and Data Security

Many studies [18, 34, 13] highlight ethical concerns and data protection as major issues. Key risks include insecure data storage, weak encryption, and unclear consent procedures in virtual environments. Without strong legal frameworks, both students and institutions remain vulnerable to privacy breaches and the misuse of sensitive information [44, 48].

Faculty Readiness and Resistance

Several studies highlight the human element—particularly faculty attitudes—as a significant barrier. Many educators feel uncomfortable teaching in metaverse environments, often due to insufficient training or low confidence [19, 16]. The lack of institutional incentives and limited collaboration with IT departments further leaves faculty without adequate support [21, 30]. This reluctance is not necessarily a sign of unwillingness, but rather a result of workload pressures and limited time [22].

Cost and Resource Constraints

Metaverse technologies come with significant financial demands. The cost of acquiring and maintaining AR/VR systems is substantial [27, 17]. Many students cannot afford the required devices, further contributing to unequal access [31, 49]. Moreover, while innovation is often encouraged, funding seldom follows, resulting in projects that remain underdeveloped or unsustainable [15].

Regulatory and Policy Gaps

Studies also highlight a clear lack of policy guidance for immersive education [42]. Legal frameworks and intellectual property rights remain undefined in most institutions. Additionally, the absence of accreditation standards makes it difficult to evaluate or formally integrate these platforms into curricula [13, 34].

Student Readiness and Acceptance

Students may be digital natives, but that doesn't mean they are automatically prepared for metaverse-based learning. The initial novelty can quickly fade, leading to disengagement [20, 32]. Learners may also face navigation challenges and feelings of social disconnection, especially when the experience lacks human interaction or emotional cues [28]. Some studies have even found that wearable devices can cause physical discomfort, negatively impacting the learning experience [27].

Evaluation and Outcome Uncertainty

Another major concern is determining how to measure success in a virtual classroom. Many remain skeptical about current assessment tools, which often lack transparency and reliability [40, 47]. AI-generated feedback can also be difficult to interpret, highlighting the need for empirical validation of these tools before they can be fully trusted [11, 37].

Curriculum Integration and Alignment

Even if the tools are ready, aligning them with the curriculum remains a hurdle. Many metaverse applications are not tailored to specific learning outcomes, and faculty often struggle to fit them into already packed schedules [43]. Integration efforts frequently lack interdisciplinary planning, resulting in isolated rather than systemic adoption [15, 42].

Mental Health and Wellbeing Risks

Finally, mental health risks are increasingly being acknowledged. Extended VR use can lead to burnout and motion sickness [20]. Moreover, if virtual environments are not thoughtfully designed, they may contribute to social isolation or exacerbate stress and anxiety, particularly among vulnerable students [21, 34].

DISCUSSION

Adopting the Metaverse in medical education offers transformative benefits, as recent studies clearly demonstrate its ability to deliver immersive, interactive, and personalized learning experiences that not only enhance skill acquisition but also foster global collaboration and promote digital health literacy [14, 55]. Through the integration of VR, AR, and AI-driven simulations, students are empowered to practice complex procedures in safe, controlled environments, receive real-time feedback, and refine critical thinking and problem-solving skills via gamified and scenario-based training [11, 12, 43, 54]. Furthermore, the Metaverse actively supports student autonomy, flexible learning pathways, and equitable access, thereby particularly benefiting underserved populations by bridging educational gaps and promoting mental health awareness [12, 39, 48, 59]. Nevertheless, several studies caution against potential drawbacks, most notably ethical concerns related to AI bias, data privacy, and the potential erosion of human empathy in clinical training [19, 48, 58]. Moreover, persistent disparities in access to advanced technologies and the digital divide remain significant challenges, which may limit both the inclusivity and overall effectiveness of Metaverse-based education [40, 45, 56, 59]. Consequently, while the Metaverse holds immense promise for revolutionizing medical education, sustained research and robust policy development are imperative to address these ethical, technical, and accessibility issues, thereby ensuring responsible and equitable implementation.

This systematic review underscores the multifaceted role of the Metaverse in reshaping medical education by enabling immersive, interactive, and globally accessible learning environments. On one hand, emerging evidence highlights its transformative potential through simulation-based training, personalized education, and interdisciplinary collaboration [1, 3, 24]; on the other hand, it simultaneously reveals persistent systemic and practical barriers that hinder widespread adoption [6, 8, 60].

One of the Metaverse's most significant strengths lies in its capacity to enhance experiential learning and simulation. For example, virtual anatomy labs, high-fidelity case simulations, and

AI-supported clinical scenarios provide students with opportunities to acquire diagnostic and procedural skills in lifelike settings [4, 5, 43]. Importantly, these tools are particularly advantageous for learners in low-resource or remote areas, as they eliminate geographic and logistical barriers while increasing exposure to complex clinical situations [23, 29, 35]. Additionally, the integration of personalized and adaptive education powered by AI further refines the learning process, fostering individualized progression and enabling data-informed feedback loops [3, 19, 53].

Beyond experiential learning, another major advantage is the facilitation of global collaboration and accessibility. Specifically, Metaverse-based platforms enable multinational classrooms and inter-institutional content sharing, thereby creating spaces for cross-cultural exchange and collaborative learning [10, 24, 31]. This, in turn, is invaluable for strengthening global health competencies and expanding equitable learning opportunities, particularly in underserved regions [23, 64].

Moreover, the Metaverse advances skill acquisition in surgical and procedural training through features such as haptic feedback systems, virtual complication management, and preoperative rehearsals [17, 20, 36, 42]. Such repetitive, low-risk practice environments significantly contribute to improved retention, reduced performance anxiety, and greater technical accuracy [5, 24, 43]. Furthermore, the integration of AI and decision support systems enriches precision learning by providing real-time diagnostics, intelligent tutoring, and adaptive assessments tailored to each learner’s specific needs [3, 16, 44].

Despite these promising developments, significant barriers persist in many institutions. Chief among these are technical and infrastructure limitations [6, 8, 13, 25]. In particular, many educational institutions lack the necessary broadband capacity, AR/VR-compatible hardware, and interoperable systems to run immersive simulations effectively [22, 44, 60]. Compounding these issues are the high costs associated with procurement, maintenance, and continual updates, which exacerbate digital inequities, especially in low and middle-income regions [19, 64].

Equally problematic are concerns related to privacy, ethics, and data security, which further complicate implementation. Because the management of sensitive learner and patient data within virtual environments demands robust encryption, strict access control, and comprehensive ethical consent systems, the absence of these safeguards in many current platforms raises substantial risks [7, 18]. In addition, the lack of national or institutional policies, regulatory benchmarks, and clearly defined intellectual property rights amplifies the threat of data breaches, surveillance, and misuse [7, 18, 57].

The human dimension, particularly faculty readiness and resistance, also plays a pivotal role. Many educators lack sufficient training, institutional incentives, and collaboration with IT specialists to fully embrace these technologies [26, 50, 59]. Without structured support and recognition for digital teaching efforts, metaverse-based pedagogy often remains underutilized [26, 31, 64]. Similarly, student readiness and digital literacy must be proactively addressed through structured onboarding, user interface training, and the integration of mental health safeguards to prevent disengagement, disorientation, or social isolation issues that disproportionately impact learners unfamiliar with immersive technologies [12, 28, 34].

In addition, the review identifies significant uncertainties in evaluation and outcome measurement. The absence of validated tools for assessing clinical competence on many Metaverse platforms, coupled with the opacity or bias in AI-generated assessments, undermines evidence-based curricular integration [3, 13, 24, 44]. These challenges are particularly pressing when institutions are accountable to standardized educational outcomes [60, 63].

Furthermore, aligning Metaverse innovations with established curricula presents a logistical hurdle. Faculty often struggle to incorporate these tools into rigid academic schedules and pre-existing learning objectives, especially in the absence of interdisciplinary coordination or dedicated time for integration [26, 30, 31]. Finally, growing concerns about student mental health and well-being cannot be overlooked. Extended VR use may lead to fatigue, motion sickness, or even social detachment, which underscores the urgent need for thoughtful instructional design and integrated wellness support systems [28, 32, 34].

Taken together, these findings clearly indicate that while the Metaverse offers extraordinary opportunities for advancing medical education, its successful integration demands a far more comprehensive approach than technological innovation alone. Addressing issues of equity, infrastructure, ethics, pedagogy, and policy in a coordinated manner is essential [12, 44, 59]. To this end, institutions must invest in capacity-building, ensure inclusive access, and establish ethical frameworks that align with professional standards [7, 18, 64]. Without such measures, the Metaverse is likely to remain an auxiliary tool rather than a core component of future medical training [23, 26, 60].

Conclusion

The integration of the Metaverse into medical education marks a transformative shift in how medical knowledge and skills are delivered. Through immersive technologies like VR, AR, and AI, it offers interactive, personalized, and globally connected learning experiences that enhance clinical training and support diverse learning needs. It also promotes equitable access and addresses digital literacy and mental well-being. However, challenges such as ethical concerns, data privacy, high costs, and infrastructure disparities must be carefully addressed. To fully harness its potential, adoption must be evidence-based, inclusive, and ethically responsible; ensuring technology to complement core humanistic values in medical training.

Recommendations

To ensure equitable access to medical education, investment in affordable XR/VR solutions and digital infrastructure is essential, especially in underserved areas. Collaborations between institutions, governments, and tech providers can bridge the digital divide. Medical schools should integrate VR/AR simulation and gamified learning to enhance skills and engagement, while adaptive platforms enable personalized, self-paced learning. Ethical guidelines for AI and data privacy, along with mental health support, are crucial. Finally, overcoming cost barriers through funding and partnerships is key to sustainability and wider access.

Future Researches

Future research on Metaverse in medical education should focus on assessing its long-term impact on clinical competency and patient outcomes. Key areas include improving access to XR/VR technologies in underserved regions, evaluating AI-driven adaptive learning for diverse needs, and addressing ethical concerns like AI bias and transparency. Studies should also explore curriculum integration, faculty readiness, psychological impacts of virtual platforms, and the effectiveness of virtual global classrooms. Additionally, research on gamification, digital health literacy, and cost-benefit analysis will help guide the sustainable integration of the Metaverse.

Implications of Metaverse in Medical Education

The metaverse is transforming medical education by providing immersive, interactive, and personalized learning through VR, AR, and AI-driven simulations. It enables students to practice complex procedures in realistic environments, receive tailored feedback, and progress at their own pace, ensuring mastery before real-world application. Fostering global collaboration, it bridges educational gaps and promotes inclusivity while offering personalized learning pathways. However, ethical concerns regarding AI transparency, data privacy, and maintaining human empathy in medical decision-making must be addressed for its full potential to be realized.

Implications for Medical Students

The metaverse is reshaping medical education by offering immersive, interactive, and personalized learning experiences through virtual and augmented reality. It allows students to practice complex procedures safely, receive instant feedback, and learn at their own pace. By enabling global collaboration and enhancing digital health literacy, it bridges educational gaps and supports skill development. However, it also raises ethical concerns around AI and data privacy, while preparing students for the challenges of modern healthcare.

Implications for Medical Schools

The metaverse is revolutionizing medical education by providing immersive, interactive learning through virtual and augmented reality, enabling realistic simulations and personalized training. It enhances global collaboration, offering accessible resources to students worldwide, including underserved regions. While promoting student autonomy, digital health literacy, and critical thinking, it also raises ethical concerns around AI, data privacy, and equitable access. Ultimately, the metaverse empowers medical schools to deliver flexible, inclusive, and future-ready education for modern healthcare.

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Author Contribution

Anila Jaleel: Conceptualization
Ghulam Farid: Concept and supervision
Umair Aziz: Manuscript writing, editing
Faisal Ikram: Data analysis, themes and subthemes
Haleema Irfan: Data analysis, themes and subthemes
Shahila Jaleel: Literature search and Data extraction
Muhammad Zahid Bashir: Review and editing
Imran A Siddiqui: Review and Proofreading
Muhammad Ali: Data analysis, Resources
Ahmad Saqib: Manuscript writing, Data extraction
Shahzaib Zahid: Method, Data extraction
Muhammad Suleman: Literature search

References

1. Uddin M, Obaidat M, Manickam S, Laghari SU, Dandoush A, Ullah H, Ullah SS. Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 2024 Nov;14(6):e1556.
2. Khan YF, Mir B. The metaverse beyond the hype: Interdisciplinary perspectives on applications, tools, techniques, opportunities, and challenges of the metaverse. Exploring the Metaverse. 2025 Jan 1:213-23.
3. Singh M, Sun D, Zheng Z. Enhancing university students' learning performance in a metaverse-enabled immersive learning environment for STEM education: A community of inquiry approach. Future in Educational Research. 2024 Sep;2(3):288-309.
4. Lo SC, Tsai HH. Design of 3D virtual reality in the metaverse for environmental conservation education based on cognitive theory. Sensors. 2022 Oct 30;22(21):8329.
5. Ipsita A, Kaki R, Liu Z, Patel M, Duan R, Deshpande L, Yuan LP, Lowell V, Maharaj A, Peppler K, Feiner S. Virtual Reality in Manufacturing Education: A Scoping Review Indicating State-of-the-Art, Benefits, and Challenges Across Domains, Levels, and Entities. arXiv preprint arXiv:2503.18805. 2025 Mar 24.
6. Rawat DB, Hagos DH. Metaverse Survey & Tutorial: Exploring Key Requirements, Technologies, Standards, Applications, Challenges, and Perspectives. arXiv preprint arXiv:2405.04718. 2024 May 7.
7. Al-Kfairy M, Alrabaee S, Alfandi O, Mohamed AT, Khaddaj S. Navigating ethical dimensions in the metaverse: Challenges, frameworks, and solutions. IEEE Access. 2025 Apr 25.
8. Wang J. Promoting the Application of Metaverse Technology in Practical Teaching for University: An Identification and Evaluation of Barriers. International Journal of Human–Computer Interaction. 2024 Nov 25:1-9.
9. Nicolosi F, de Laurentis C, Giussani C, Marcus HJ, Spena G, Ammar A. Mixed Reality and Metaverse.

InEthical Challenges for the Future of Neurosurgery 2024 Nov 16 (pp. 141-159). Cham: Springer Nature Switzerland.
10. Joshi R, Pandey K, Kumari S. A metaverse: Significance and dimensions in various sectors. In2024 11th International Conference on Computing for Sustainable Global Development (INDIACom) 2024 Feb 28 (pp. 1781-1786). IEEE
11. Li Q, Duan H, Zhou X, Sun X, Tao L, Lu X. The use of metaverse in medical education: A systematic review. Clin Med (Lond). 2025 May;25(3):100315.
12. Lau J, Dunn N, Qu M, Preyra R, Chan TM. Metaverse technologies in acute care medical education: A scoping review. AEM Education and Training. 2025 Feb;9(1):e11058.
13. Ghaempanah F, Moasses Ghafari B, Hesami D, et al. Metaverse and its impact on medical education and health care system: a narrative review. Health Sci Rep. 2024;7:e70100. doi:10.1002/hsr2.70100.
14. Arpaci I, Bahari M. Investigating the role of psychological needs in predicting the educational sustainability of Metaverse using a deep learning-based hybrid SEM-ANN technique. Interactive Learning Environments. 2024 Jul 2;32(6):2957-69.
15. Chauhan A, Angadi PV. Metaverse in Dentistry: Assessment of Knowledge Regarding its Application among Dental Students and Dental Professionals. Annals of Dental Specialty. 2024;12(2-2024):6-14.
16. Jin SV. “In the Metaverse We (Mis) trust?” Third-Level Digital (In) equality, Social Phobia, Neo-Luddism, and Blockchain/Cryptocurrency Transparency in the Artificial Intelligence-Powered Metaverse. Cyberpsychology, Behavior, and Social Networking. 2024 Jan 1;27(1):64-75.
17. Kulkarni C, Quraishi A, Raparthi M, Shabaz M, Khan MA, Varma RA, Keshta I, Soni M, Byeon H. Hybrid disease prediction approach leveraging digital twin and metaverse technologies for health consumer. BMC Medical Informatics and Decision Making. 2024 Apr 5;24(1):92.
18. Letafati M, Otoum S. Digital healthcare in the metaverse: Insights into privacy and security. IEEE Consumer Electronics Magazine. 2023 Nov 20;13(3):80-9.
19. Lewis KO, Popov V, Fatima SS. From static web to metaverse: reinventing medical education in the post-pandemic era. Annals of medicine. 2024 Dec 31;56(1):2305694.
20. Mizuta R, Maeda N, Tashiro T, Suzuki Y, Kuroda S, Ishida A, Oda S, Watanabe T, Tamura Y, Komiya M, Urabe Y. Effectiveness of Metaverse Space–Based Exercise Video Distribution in Young Adults: Randomized Controlled Trial. JMIR mHealth and uHealth. 2024 Jan 16;12:e46397.
21. Ramos FN, Bernstein RA, Ezawa ID. Assessing Predictive Factors of Attitudes Toward Peer-Supported Mental Health Interventions in the Metaverse: Mixed Methods Study. JMIR XR and Spatial Computing (JMXR). 2024 Aug 22;1(1):e57990.
22. Shwedeh F. Harnessing digital issue in adopting metaverse technology in higher education institutions: Evidence from the United Arab Emirates. International Journal of Data & Network Science. 2024 Jan 1;8(1).
23. Farrukh K. Metaverse in medical education: a paradigm shift. Pakistan Journal of Medical Sciences. 2024 Jan;40(1Part-I):255.
24. Jagatheesaperumal SK, Ahmad K, Al-Fuqaha A, Qadir J. Advancing education through extended reality and internet of everything enabled metaverses: applications, challenges, and open issues. IEEE Transactions on Learning Technologies. 2024 Jan 26;17:1120-39.
25. Rane N, Choudhary S, Rane J. Healthcare Metaverse: applications, challenges, and future development. Challenges, and Future Development (November 3, 2023). 2023 Nov 3.
26. Suh I, McKinney T, Siu KC. Current perspective of metaverse application in medical education, research and patient care. InVirtual worlds 2023 Apr 18 (Vol. 2, No. 2, pp. 115-128). MDPI.
27. Kim EJ, Kim JY. The metaverse for healthcare: trends, applications, and future directions of digital therapeutics for urology. International Neurourology Journal. 2023 May 24;27(Suppl 1):S3.
28. Coşkun AB, Elmaoğlu E. Examining the impact of adolescents' metaverse perception on e-health literacy and perceptions of healthy living. Archives of Physiotherapy & Global Researches. 2023 Jul 1;26(2).
29. Zaman U. Metaverse going beyond adoption: the next frontier for global healthcare. Frontiers in Public Health. 2023 May 2;11:1194285.
30. Prakash A, Haque A, Islam F, Sonal D. Exploring the potential of metaverse for higher education: Opportunities, challenges, and implications. Metaverse Basic and Applied Research. 2023(2):13.
31. Imannezhad S, Vahedian-Shahroodi M, Shariati K, Mansourzadeh A, Saeedi M. Metaverse in Education; An Overview of Systematic Reviews. Medical Education Bulletin. 2023 Jun 1;4(2):731-43.
32. Shao L, Tang WE, Zhang Z, Chen X. Medical metaverse: Technologies, applications, challenges and future.

Journal of Mechanics in Medicine and Biology. 2023 Mar 12;23(02):2350028.
33. Alvarez-Risco A, Del-Aguila-Arcentales S, Rosen MA, Yáñez JA. Social cognitive theory to assess the intention to participate in the Facebook metaverse by citizens in Peru during the COVID-19 pandemic. Journal of Open Innovation: Technology, Market, and Complexity. 2022 Aug 13;8(3):142.
34. Benrimoh D, Chheda FD, Margolese HC. The best predictor of the future—the metaverse, mental health, and lessons learned from current technologies. JMIR Mental Health. 2022 Oct 28;9(10):e40410.
35. Ganapathy K. Metaverse and healthcare: A clinician's perspective. Apollo Medicine. 2022 Dec;19(4):256-61.
36. Gobeka HH, Gülyeşil FF, Yozgat Z, Sabaner MC. Quality assessment and comparison of two-and three-dimensional YouTube videos as additional educational tools for cataract surgery:“METAVERSE”. Irish Journal of Medical Science (1971-). 2023 Oct;192(5):2427-33.
37. Huynh-The T, Pham QV, Pham XQ, Nguyen TT, Han Z, Kim DS. Artificial intelligence for the metaverse: A survey. Engineering Applications of Artificial Intelligence. 2023 Jan 1;117:105581.
38. Jeon H, Shin H, Woo J. User experience and interface assessment for metaverse platforms on nurses and nursing students: A cross-sectional study. Nurse Education Today. 2024 Aug 1;139:106222.
39. Petrigna L, Musumeci G. The metaverse: A new challenge for the healthcare system: A scoping review. Journal of functional morphology and kinesiology. 2022 Aug 30;7(3):63.
40. Weinberger M. What is metaverse? a definition based on qualitative meta-synthesis. Future Internet. 2022 Oct 28;14(11):310.
41. Skalidis I, Muller O, Fournier S. CardioVerse: The cardiovascular medicine in the era of Metaverse. Trends in cardiovascular medicine. 2023 Nov 1;33(8):471-6.
42. Kala N. Revolutionizing medical education with metaverse. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022 Jul;8(4):26-32.
43. Pregowska A, Osial M, Dolega-Dolegowski D, Kolecki R, Proniewska K. Information and communication technologies combined with mixed reality as supporting tools in medical education. Electronics. 2022 Nov 17;11(22):3778.
44. Bansal G, Rajgopal K, Chamola V, Xiong Z, Niyato D. Healthcare in metaverse: A survey on current metaverse applications in healthcare. Ieee Access. 2022 Nov 4;10:119914-46.
45. Almarzouqi A, Aburayya A, Salloum SA. Prediction of user’s intention to use metaverse system in medical education: A hybrid SEM-ML learning approach. IEEE access. 2022 Apr 21;10:43421-34.
46. Wang G, Badal A, Jia X, Maltz JS, Mueller K, Myers KJ, Niu C, Vannier M, Yan P, Yu Z, Zeng R. Development of metaverse for intelligent healthcare. Nature machine intelligence. 2022 Nov;4(11):922-9.
47. Lin H, Wan S, Gan W, Chen J, Chao HC. Metaverse in education: Vision, opportunities, and challenges. In2022 IEEE International Conference on Big Data (Big Data) 2022 Dec 17 (pp. 2857-2866). IEEE.
48. Yang Y, Siau K, Xie W, Sun Y. Smart health: Intelligent healthcare systems in the metaverse, artificial intelligence, and data science era. Journal of Organizational and End User Computing (JOEUC). 2022 Jan 1;34(1):1-4.
49. Gurusamy A, Mohamed IA. The role of AI and machine learning in full stack development for healthcare applications. Journal of Knowledge Learning and Science Technology ISSN: 2959-6386 (online). 2021 Mar 14;1(1):116-23.
50. Kye B, Han N, Kim E, Park Y, Jo S. Educational applications of metaverse: possibilities and limitations. Journal of educational evaluation for health professions. 2021 Dec 13;18.
51. Thomason J. Metahealth-how will the metaverse change health care?. Journal of Metaverse. 2021 Dec 26;1(1):13-6.
52. Tene T, Vique López DF, Valverde Aguirre PE, Orna Puente LM, Vacacela Gomez C. Virtual reality and augmented reality in medical education: an umbrella review. Front Digit Health. 2024 Mar 14;6:1365345. doi:10.3389/fdgth.2024.1365345. PMID: 38550715; PMCID: PMC10973128
53. Lee H, Patel S. Personalized learning pathways in the Metaverse: empowering medical students through immersive technology. 2024.
54. Du Y, Yang Q. Clinical skills training of Metaverse-based learning: a systematic review. Int J Acad Res Prog Educ Dev. 2024 Jun;13(3). doi:10.6007/IJARPED/v13-i3/21832.
55. Wang Y, Duan B, Chen X, Song Y, Liu X. The application of metaverse in mental health. Front Public Health. 2025 Apr 10;13:1463494. doi: 10.3389/fpubh.2025.1463494. PMID: 40276352; PMCID: PMC12018439.
56. Han SP, Kumwenda B. Bridging the digital divide: Promoting equal access to online learning for health

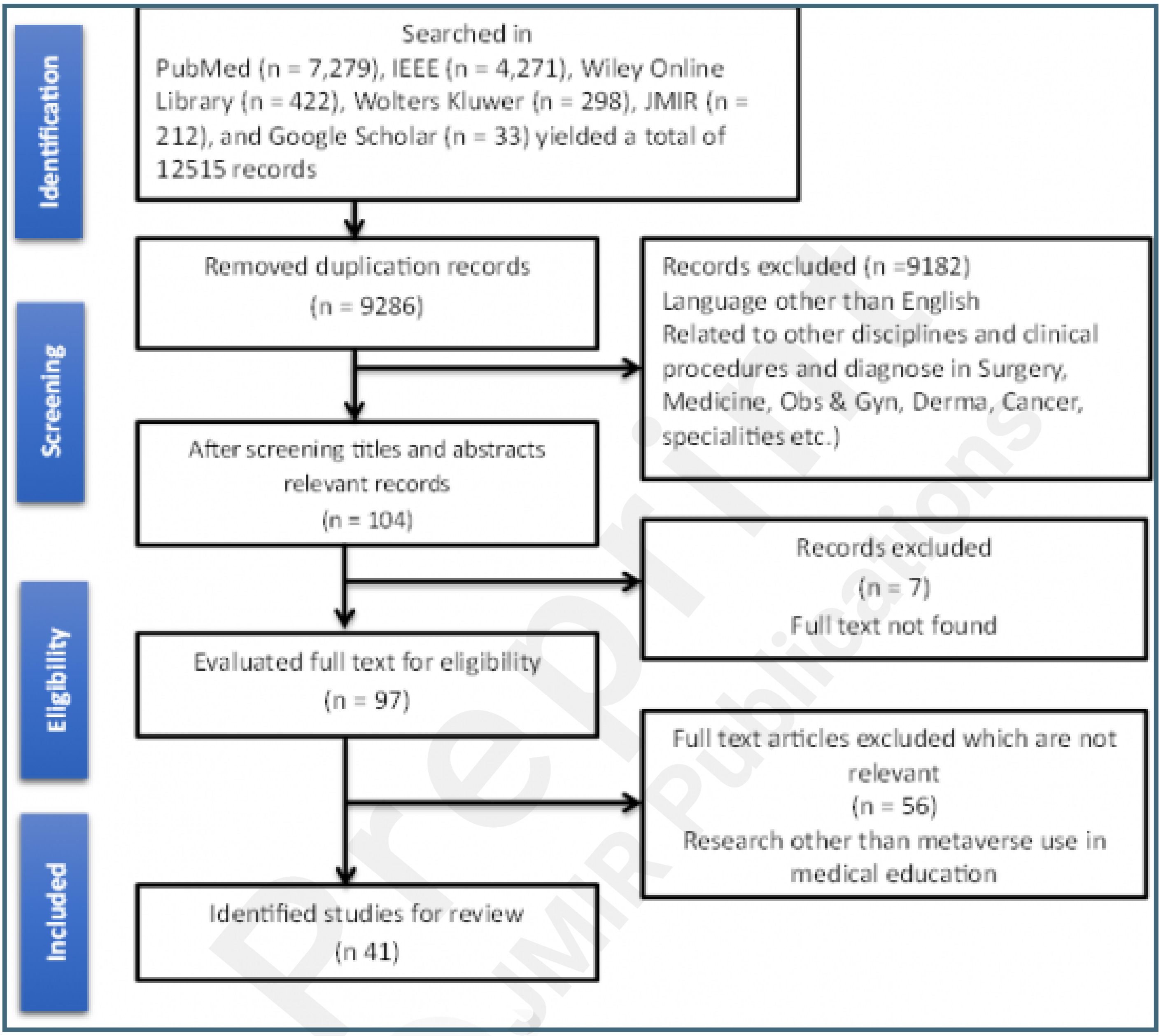
professions in an unequal world. Med Educ. 2025 Jan;59(1):56-64. doi: 10.1111/medu.15455. Epub 2024 Jun 11. PMID: 38860836.

57. Kahraman F, Aktas A, Bayrakceken S, Çakar T, Tarcan HS, Bayram B, Durak B, Ulman YI. Physicians' ethical concerns about artificial intelligence in medicine: a qualitative study: "The final decision should rest with a human". Front Public Health. 2024;12:1428396. doi:10.3389/fpubh.2024.1428396.
58. Alkaeed M, Qayyum A, Qadir J. Privacy preservation in Artificial Intelligence and Extended Reality (AI-XR) metaverses: A survey. Journal of Network and Computer Applications. 2024 Aug 2:103989.
59. Bernardes A, Gardim L, Araújo AAC, Jensen R, Motta RA, Almeida DM, Lima RR, Peres HHC. Exploring the metaverse in the education of healthcare students: A scoping review. Rev Lat Am Enfermagem. 2024 Oct 25;32:e4347. doi: 10.1590/1518-8345.7256.4347. PMID: 39476135; PMCID: PMC11526252.
60. Popov V, Mateju N, Jeske C, Lewis KO. Metaverse-based simulation: a scoping review of charting medical education over the last two decades in the lens of the 'marvelous medical education machine'. Ann Med. 2024 Dec;56(1):2424450. doi: 10.1080/07853890.2024.2424450. Epub 2024 Nov 13. PMID: 39535116; PMCID: PMC11562026.
61. Okamoto S, Kataoka M, Itano M, et al. AI-based medical ethics education: examining the potential of large language models as a tool for virtue cultivation. *BMC Med Educ*. 2025;25:185. doi:10.1186/s12909-025-06801-y.
62. Li K, Lau BP, Yuan X, Ni W, Guizani M, Yuen C. Toward ubiquitous semantic metaverse: Challenges, approaches, and opportunities. IEEE Internet of Things Journal. 2023 Aug 4;10(24):21855-72.
63. Huang H, Yin J, Lv F, Zhang Y, Liu Y, Wang L. A study on the impact of open source metaverse immersive teaching method on emergency skills training for medical undergraduate students. *BMC Med Educ*. 2024;24:859. doi:10.1186/s12909-024-05862-9.
64. Zaidi SSB, Adnan U, Lewis KO, Fatima SS. Metaverse-powered basic sciences medical education: bridging the gaps for lower middle-income countries. Ann Med. 2024 Dec;56(1):2356637. doi: 10.1080/07853890.2024.2356637. Epub 2024 May 24. PMID: 38794846; PMCID: PMC11132556.
65. Rocha T, Ribeiro A, Oliveira J, Nunes R, Carvalho D, Paredes H, Martins P. 3D Modelling to Address Pandemic Challenges: A Project-Based Learning Methodology. arXiv preprint arXiv:2411.08730. 2024 Nov 13.
66. Hutson, J., & Ratican, J. (2023). Individuality and the collective in AI agents: Explorations of shared consciousness and digital homunculi in the metaverse for cultural heritage. *Metaverse*, *4*(2).
67. Thomas, J., Kuhail, M. A., & AlBeyahi, F. (2024). The metaverse, religious practice and wellbeing: A narrative review. *Cyberpsychology, Behavior, and Social Networking*, *27*(1), 57-63.
68. Lewis, K. O., Popov, V., & Fatima, S. S. (2024). From static web to metaverse: reinventing medical education in the post-pandemic era. *Annals of medicine*, *56*(1), 2305694.

Supplementary Files

Figures

The prisma diagram of the study.



Multimedia Appendixes

Overview of the selected studies on adoption and challenges of metaverse technologies into medical education.
URL: http://asset.jmir.pub/assets/646c7a4a41e86a0fa80a90db2efed273.docx