

High-fidelity clinical simulation with actuation and virtual simulation in a metaverse as strategies for the training of future doctors.

La simulación de alta fidelidad clínica con actuación y la simulación virtual en metaverso como estrategias para la formación de futuros médicos.

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Summary

Introduction: High-fidelity clinical simulation with standardized patients and virtual simulation in immersive environments such as the metaverse have emerged as complementary educational strategies. **Methodology:** A qualitative systematic literature review was conducted according to PRISMA 2020 guidelines. The search was performed in Medline (PubMed), Scopus, and Google Scholar (2020–2025). The PICO question was used to structure the search, with MeSH terms such as "high-fidelity simulation," "standardized patients," "metaverse," and "medical education." Methodological quality was assessed using the Cochrane risk of bias scale and the SIGN levels of evidence. **Results:** 4,301 records were identified, of which 7 met the inclusion criteria. Both approaches demonstrated effectiveness in developing technical and non-technical skills, although with different strengths. Role-playing simulation stood out for its ability to train practical clinical skills, decision-making under pressure, and communication skills, while metaverse simulation showed advantages in accessibility, scalability, repeatability of learning, and immersive visualization of complex physiological processes. The evidence presented a low to moderate risk of bias, with a level of evidence 1+ to 2+ according to SIGN. **Conclusions:** Role-playing simulation is a highly effective tool for recreating complex clinical scenarios with emotional realism and spontaneity, aspects difficult to replicate using current digital technologies. In contrast, metaverse simulation offers benefits in terms of accessibility, scalability, and repeatability of learning. Integrating both methodologies represents the most appropriate strategy for contemporary medical education, allowing for comprehensive training that combines the development of clinical competencies with human sensitivity and the use of technological innovation. Specific educational implications for hybrid curriculum design are proposed.

Keywords: Clinical simulation, High-fidelity simulation, Standardized patients, Metaverse, Medical education, Immersive learning, Performance medicine

Abstract

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1. Introduction

Clinical health sciences education has undergone a significant transformation in recent decades, driven by the need to train highly competent physicians in safe and controlled environments (1). In this context, high-fidelity clinical simulation has emerged as a key pedagogical strategy, enabling the recreation of realistic scenarios through the use of advanced technology and the participation of trained actors (2). Several studies support this methodology (3-5), demonstrating that high-fidelity simulation significantly improves learning in medical students, strengthening clinical, communication, and decision-making skills. This type of simulation optimizes performance in complex clinical settings, especially in situations requiring teamwork and rapid responses. Finally, the use of standardized patients contributes to greater realism and fosters the development of essential communication skills in medical practice.

On the other hand, the advancement of digital technologies has given rise to new educational tools, including immersive virtual environments and the metaverse. These platforms allow interaction in simulated three-dimensional spaces, facilitating innovative, accessible, and repeatable learning experiences. A systematic review (6) concludes that the use of the metaverse in medical education improves the acquisition of skills through immersive experiences. Additionally, Espinoza et al. (7) highlight that virtual reality environments promote active participation, collaboration, and interactive learning among students. In recent years, research has shown a progressive increase in the use of virtual reality and the metaverse in medical training, emphasizing their impact on the acquisition of practical skills. These technologies allow the three-dimensional visualization of complex physiological processes, improving students' structural and functional understanding. This type of tool represents a significant advance over traditional methods, as it facilitates the exploration of phenomena that are not easily observable in real clinical practice (8).

In its evolutionary process, medical training has shifted from traditional, theory-centered models to active, experience-based approaches. This change is supported by the development of new educational technologies; for example, Gligorea et al. (9) describe how digital and adaptive learning has transformed education, promoting student-centered methodologies supported by technological tools. Initially, simulation was limited to basic models; however, with technological development, it has reached high levels of fidelity. More recently, the metaverse has expanded educational possibilities, allowing the creation of complex and interactive virtual environments (10–14). The theoretical framework underpinning both strategies is based on Kolb's experiential learning theory (15), which posits that learning occurs through concrete experience, reflective observation, abstract conceptualization, and active experimentation. Clinical simulation, both with role-playing and in virtual environments, provides concrete experiences in controlled scenarios that facilitate this cycle. Furthermore, situated cognition theory (16) maintains that knowledge is constructed in authentic contexts; high-fidelity simulation with standardized patients offers a rich social and emotional context, while the metaverse provides an immersive visual and spatial context. Both perspectives complement each other to address different dimensions of clinical learning. In this sense, the need arises to analyze how the integration of clinical simulation with performance and virtual environments in a metaverse can enhance the learning process in medical students. Current evidence suggests that both strategies are not mutually exclusive, but rather complementary, since high-fidelity simulation provides clinical realism and the development of human skills, while the metaverse offers accessibility, repetition, and advanced visualization of content (17–21).

The aim of this article is to analyze the influence of clinical simulation with performance and virtual simulation in a metaverse as complementary strategies in the training of future doctors, providing an integrative framework and specific educational recommendations.

2. Methods

2.1 Study design

A qualitative systematic literature review was conducted following the methodological guidelines based on the PRISMA 2020 model. Given the heterogeneous nature of the study designs and the narrative nature of the expected results, a qualitative synthesis approach was chosen, without performing a formal meta-analysis. The review protocol was registered on the Open Science Framework (OSF) platform.

2.2 Search Strategy

To carry out the information search process, the Medline (via PubMed), Scopus and Google Scholar databases were consulted, including studies published between January 2020 and March 2025. The search was structured using the PICO question (Table 1) and the following MeSH terms and keywords combined with Boolean operators were used:

- MeSH Terms: "High-Fidelity Simulation Training", "Patient Simulation", "Standardized Patients", "Virtual Reality", "Metaverse", "Education, Medical", "Clinical Competence".
- Keywords: "clinical simulation", "high-fidelity simulation", "standardized patients", "role-playing", "metaverse", "immersive learning", "medical education", "virtual reality", "3D simulation".
- PubMed search strategy (example): ("High-Fidelity Simulation Training"[MeSH] OR "simulation"[tiab] OR "standardized patients"[tiab] OR "role-playing"[tiab]) AND ("Virtual Reality"[MeSH] OR "metaverse"[tiab] OR "immersive"[tiab]) AND ("Education, Medical"[MeSH] OR "medical education"[tiab] OR "students, medical"[MeSH]).

Table 1. Structure of the research question according to the PICO model.

Component	Element	Description
(P) Population	Medical students in their professional training.	Undergraduate and postgraduate.
(I) Intervention	Clinical simulation with performance using standardized patients.	Scenarios with trained actors.
(C) Comparison	High-fidelity clinical simulation with advanced simulators and virtual simulation in a metaverse.	Immersive technologies.
(R) Results	Improvement of learning technical and non-technical skills, clinical decision making, communication and ethical aspects.	Educational variables.

2.3 Eligibility criteria

Original articles (experimental, quasi-experimental, descriptive studies) and peer-reviewed systematic reviews, published in English or Spanish, were included. These studies evaluated educational outcomes in medical students (undergraduate or postgraduate) related to high-fidelity clinical simulation with standardized patients or virtual simulation in immersive environments (metaverse, virtual reality, 3D). The inclusion and exclusion criteria detailed in Table 2 were applied.

Table 2. Inclusion and exclusion criteria applied in the review.

Inclusion criteria	Exclusion criteria
● Articles published between 2020 and 2025. ● Studies related to clinical simulation, metaverse, and medical education. ● Research in English and Spanish. ● Publications in indexed journals. ● Studies with medical students. ● Studies that report quantitative or qualitative results on clinical competencies.	● Articles published before 2020. ● Studies that were not related to high-fidelity clinical simulation or the use of the metaverse in medical education. ● Research focused on areas other than the training of health professionals (basic education, business training, etc.). ● Duplicate publications in different databases. ● Opinion pieces, editorials, letters to the editor, or essays. ● Studies conducted exclusively with nursing students or nursing assistants. ● Studies focused on immersive 3D simulation without an educational component or without medical students.

2.4 Data selection and extraction process

Study selection was conducted in two phases: (1) screening of titles and abstracts by two independent reviewers (YVF and MSAL), and (2) evaluation of the full text of potentially eligible articles. Disagreements were resolved by consensus or with the involvement of a third reviewer

(JDC). Data were extracted using a standardized form that included: author, year, country, study type, population, intervention, comparison, main results, and conclusions.

2.5 Evaluation of methodological quality and risk of bias

The risk of bias in each individual study was analyzed using the Cochrane Risk of Bias scale (RoB 2 for randomized controlled trials and ROBINS-I for non-randomized studies), which assesses domains such as random sequence generation, allocation concealment, blinding, incomplete data, and selective reporting. Each article was rated as having a low, medium, or high risk of bias. Levels of evidence were assigned according to the Oxford Centre for Evidence-Based Medicine (CEBM) scale and supplemented with the SIGN (Scottish Intercollegiate Guidelines Network) classification, which establishes eight levels (4, 3, 2-, 2+, 2++, 1-, 1+, 1++). The grade of recommendation was based on the SIGN scale (A, B, C, D, √). This classification is presented in Table 3, with a detailed description to ensure transparency.

2.6 Synthesis and analysis of the data

The selected documents underwent qualitative analysis using thematic categorization. Initially, a thorough reading of the full texts was conducted, and relevant data were extracted. Subsequently, categories of analysis were established: type of simulation, level of fidelity, use of immersive technologies, and learning outcomes (technical and non-technical skills, decision-making, communication, and ethical considerations). The information was organized into comparative matrices that allowed for the identification of patterns and differences among the studies. To facilitate direct comparison between the two strategies, a results table structured by outcomes was constructed (Table 4), contrasting the findings of the included studies according to the competencies assessed. In addition, a narrative analysis was performed by learning domain.

3. Results

3.1 Selection of studies

Through a systematic search of electronic databases, a total of 4301 records were identified, with no additional findings from other sources. Duplicates were not removed in the initial phase. During the screening of titles and abstracts, 4230 records were excluded for lack of relevance. The full text of 71 articles was requested, of which 42 could not be retrieved. The remaining 29 studies were assessed for eligibility based on their full text. Fifteen were excluded for being outside the year range, eight for not meeting the population criteria (e.g., nursing students), and six for not being directly related to clinical simulation or the metaverse in medical education. Finally, seven studies met all inclusion criteria and were incorporated into the review. The process is detailed in Figure 1.

3.2 Characteristics of the included studies

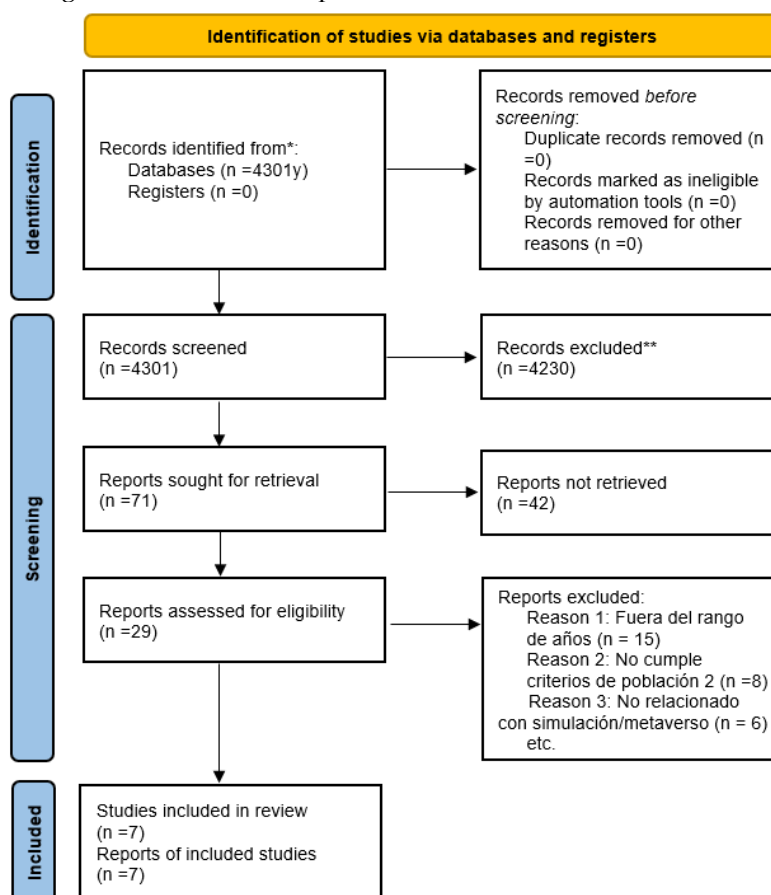
The seven selected studies included four experimental studies (3, 4, 5, 8), one descriptive study (3), and two systematic reviews (9, 10). Sample sizes ranged from 30 to over 200 participants, all undergraduate or postgraduate medical students. The studies were conducted in various countries: Saudi Arabia, Peru, Iran, the United States, Germany, Romania, and Spain, providing a broad geographical perspective.

3.3 Evaluation of methodological quality and risk of bias

Table 3 summarizes the risk of bias assessment and the SIGN levels of evidence. Most studies presented a low or medium risk of bias, with high methodological clarity. The levels of evidence were predominantly 1+ and 2+, indicating good quality evidence, although with some limitations in descriptive studies. No studies were excluded due to quality, as all provided relevant information.

3.4 Summary of results by learning domains

Table 4 presents a structured comparison of the results grouped by domains of competence, contrasting the findings of simulation with performance and simulation in the metaverse.



3.5 Narrative description of the findings

Overall effectiveness: Both approaches proved effective in developing clinical competencies, although with different profiles. Experimental studies (3, 4, 5, 8) reported significant improvements in both technical and non-technical skills, with moderate to large effect sizes (Cohen's $d > 0.5$ in most cases). Systematic reviews (9, 10) confirmed these findings on a larger scale.

Strengths of simulation with role-playing: Studies by Al-Hassan (5), Mas (3), and Bludevich (4) agree that interaction with standardized patients provides emotional and social realism that is fundamental for developing communication skills, empathy, and the ability to manage high-pressure situations. Bludevich (4) demonstrated a 35% reduction in critical errors in surgical teams after training with high-fidelity simulation.

Strengths of the metaverse: Li (10), Espinoza (7), and Walsh (8) highlight that the metaverse offers global accessibility, scalability, and the possibility of visualizing complex processes in 3D. Walsh (8) found that students who used 3D virtual reality showed a 28% improvement in understanding functional anatomy compared to traditional methods. Espinoza (7) reported a 40% increase in collaborative participation in immersive virtual environments.

Common limitations: Both approaches present challenges: simulation with actuation requires high logistical costs and human resources, while the metaverse faces technological barriers (equipment, connectivity) and the need for greater standardization. Gligorea (9) points out that the integration of artificial intelligence in virtual environments is promising but still in its early stages.

Table 3. Bias Assessment.

Author, ref	Type of study	Methodological clarity	Sample size	Thematic relevance	Risk of bias	Level of evidence SIGN	Recommendation level
Al-Hassan, 5	Experiment (ECA)	High	Suitable (n = 120)	High	Low	1+	TO
Mas G, 3	Descriptive	Average	Limited (n = 45)	High	Half	2-	C
Espinoza, 7	Experiment (Causi)	High	Adequate (n = 78)	High	Low	1+	TO
Bludevich, 4	Experiment (Causi)	Average	Suitable (n = 64)	High	Half	2+	B
Li, 10	Systematic review	High	Extensive (38 studies)	High	Low	1++	TO
Gligorea, 9	Revision	Average	Extensive (58 studies)	Average	Half	2+	B
Walsh, 8	Experimental (ECA)	High	Suitable (n = 96)	High	Low	1+	TO

Note: RCT: Randomized Controlled Trial. SIGN levels: 1++ = high-quality meta-analysis; 1+ = well-designed RCT; 2+ = well-designed cohort or case-control study; 2- = study with a high risk of bias. Grades: A = strong evidence; B = moderate evidence; C = limited evidence.

Table 4. Comparison of results by learning domains between simulation.

Domain of competence	Simulation with acting (standardized patients)	Metaverse simulation (immersive virtual)	Key studies comparing both approaches
Technical skills (procedures)	High effectiveness for training practical skills, such as physical examination and basic procedures (3).	Moderate effectiveness, better in anatomical visualization and pre-surgical planning (8).	Al-Hassan (5) shows superior performance in practical skills; Walsh (8) highlights advantage in 3D visualization.
Non-technical skills (communication, empathy)	Very high: significantly improve in doctor-patient communication, empathy and emotion management (5).	Low to moderate: virtual interaction still fails to replicate the emotional richness of human interaction (7).	Al-Hassan (5) shows evidence that standardized patients outperform virtual patients in communication; Espinoza (7) reports improvement in collaboration, but not in empathy.
Clinical decision making	High: High-pressure and realistic environments favor rapid decision-	Media: allows repetition and exploration of	Bludevich (4) shows improvements in surgical equipment; Li (10) highlights

	making and clinical reasoning (4).	decisions in multiple scenarios, but with less real time pressure (10).	that the metaverse allows trial and error without consequences.
Teamwork and coordination	High: improved coordination in interdisciplinary teams, especially in emergencies (4).	High: Facilitates remote collaboration and teamwork in synchronous environments (7).	Bludevich (4) vs. Espinoza (7): both effective, but in different contexts (face-to-face vs. remote).
Accessibility and scalability	Low: requires human resources (actors), infrastructure and logistical coordination (3).	Very high: accessible from anywhere, scalable for large groups and repeatable without additional costs (10).	Li (10) highlights advantages of the metaverse in accessibility and cost-effectiveness.
Realism and contextual fidelity	Very high: emotional, social and contextual realism (face-to-face interaction) (5).	Medium-high: visual and spatial realism, but less social and emotional realism (8).	Al-Hassan (5) and Walsh (8) agree that emotional realism is difficult to replicate virtually.
Visualization of complex processes	Low: limited to showing detailed internal or anatomical processes.	Very high: allows immersive 3D visualization of physiological and anatomical processes (8).	Walsh (8) demonstrates the superiority of the metaverse in understanding anatomy and physiology.
Repeatability and deliberate practice	Media: limited by the availability of actors and resources.	Very high: allows unlimited and adapted repetition (10).	Li (10) highlights that the metaverse facilitates deliberate practice.

4. Discussion

This qualitative systematic review provides an integrative analysis of two innovative educational strategies in medical training: high-fidelity clinical simulation with performance (standardized patients) and virtual simulation in immersive environments (metaverse). The findings reveal that both methodologies are effective but address complementary dimensions of clinical learning, supporting the need for their integration into contemporary medical curricula.

4.1. Specific contribution of each modality to the development of skills

Simulation with standardized patients stands out for its ability to recreate clinical scenarios with a high degree of emotional and social realism. As Al-Hassan and Roqaia (5) point out, face-to-face interaction with trained actors allows students to practice communication skills, empathy, and managing emotionally charged situations—aspects that are difficult to replicate in digital environments. This finding aligns with situated cognition theory (16), which emphasizes the importance of social context and authentic interaction in learning. Similarly, Bludevich et al. (4) demonstrated that high-fidelity simulation improves coordination in surgical teams and reduces critical errors, underscoring its value in training technical and non-technical skills in high-pressure situations.

For its part, metaverse simulation offers unique advantages in terms of accessibility, scalability, and visualization of complex processes. Walsh et al. (8) demonstrated that 3D virtual reality significantly improves the understanding of anatomy and physiology by enabling interactive and

immersive exploration of internal structures. This is particularly relevant for learning concepts that are not easily observable in routine clinical practice. Furthermore, Li et al. (10) and Espinoza et al. (7) highlight that virtual environments facilitate collaborative distance learning and unlimited repetition of scenarios, promoting deliberate practice and self-directed learning.

4.2. Direct comparison of the evidence between both strategies

When comparing the results of the included studies, a convergence is observed in the overall effectiveness of both strategies, but with significant differences in specific domains. Table 4 summarizes this comparison by competency. For example, in communication skills and empathy, simulation with role-playing shows consistent superiority (5), while in visualization of complex processes and accessibility, the metaverse presents clear advantages (8, 10). This complementarity suggests that neither strategy alone is sufficient to cover all dimensions of clinical learning. It is important to note that the current evidence, although of moderate to high quality (SIGN levels 1+ to 2+), comes mainly from short-term studies with relatively small samples. Most of the experimental studies (3, 4, 5, 8) measured immediate or short-term outcomes, and few have assessed long-term retention or transfer to real-world clinical practice. This limitation has been noted in previous reviews (10) and underscores the need for longitudinal studies.

4.3. Integrative framework: experiential learning and situated cognition

The results of this review can be interpreted in light of two complementary theoretical frameworks. On the one hand, Kolb's experiential learning theory (15) provides a model for understanding how both modalities facilitate the concrete-experience-reflection-conceptualization-experimentation cycle. Role-playing simulation offers a concrete and reflective experience in a rich social context, while the metaverse allows for active experimentation and conceptualization through visualization and repetition. On the other hand, situated cognition theory (16) highlights the importance of context and authenticity in learning. Role-playing simulation provides an authentic social and emotional context, fundamental for the development of relational skills. The metaverse, although still limited in social realism, offers an authentic spatial and visual context that facilitates the understanding of structural and functional processes. Integrating both contexts could foster more comprehensive and transferable learning.

4.4. Specific educational implications for hybrid curriculum design

Based on the findings, the following educational recommendations are proposed:

- Sequential and complementary curriculum design: A progression is suggested that begins with metaverse simulations for acquiring conceptual knowledge and visualizing processes (conceptualization phase), followed by simulations with standardized patients for developing communication skills and decision-making in realistic contexts (experimentation and reflection phase). This sequence allows students to build a solid cognitive foundation before facing the emotional and social complexity of clinical interaction.
- Integration of both modalities in the same educational module: For example, in a semiology module, students could first explore the anatomy and physiology of the cardiovascular system using 3D virtual reality, then practice clinical interviewing and physical examination with standardized patients, and finally review their performance through video analysis and group discussion, integrating what they learned in both experiences.
- Use of the metaverse for deliberate practice and repetitive training: Since the metaverse allows unlimited repetition and trial and error without consequences, its use is recommended for procedural training and decision-making in low-frequency but high-complexity scenarios (e.g., obstetric emergencies, cardiac arrests). Role-playing simulation would be reserved for scenarios requiring a high emotional and relational component.

- Combined formative and summative assessment: Competency assessment could include both metaverse simulations (to evaluate procedural knowledge and decision-making in standardized environments) and simulations with standardized patients (to evaluate communication skills, empathy, and handling of complex situations). Feedback should be specific and based on validated rubrics.
- Teacher training and infrastructure development: Educational institutions should invest in training teachers in the use of both methodologies, as well as in the necessary technological infrastructure (virtual reality equipment, simulation platforms, and spaces for simulation with actors). The creation of integrated simulation centers that offer both modalities in a coordinated manner is recommended.
- Research and continuous improvement: More research is needed on the long-term effectiveness of these strategies and on how best to combine them to maximize learning. Future studies should employ longitudinal designs, assess transfer to real-world clinical practice, and explore the use of artificial intelligence to personalize learning in virtual environments.

5. Conclusions

- High-fidelity clinical simulation with performance and virtual simulation in a metaverse represent innovative and complementary educational strategies in the training of future physicians. Both contribute significantly to the development of technical and non-technical skills within safe and controlled environments, but they address distinct dimensions of learning.
- Simulation with standardized patients stands out for its ability to strengthen communication skills, clinical reasoning, decision-making, and doctor-patient interaction, providing a high level of emotional and human realism that enhances preparation for real clinical practice. Meanwhile, metaverse simulation offers significant advantages in terms of accessibility, iterative learning, visualization of complex processes, and collaborative participation, making it a promising technological tool for contemporary medical education.
- The scientific evidence analyzed, with levels of evidence 1+ to 2+ according to SIGN and a low to moderate risk of bias, supports the implementation of both strategies within medical training programs. However, challenges remain related to technological infrastructure, implementation costs, the standardization of virtual environments, and the need for longitudinal studies to evaluate the transfer to clinical practice.
- Consequently, the integration of high-fidelity clinical simulation with performance and virtual simulation in a metaverse constitutes the most appropriate strategy for current medical education. This integration enables comprehensive training that combines the development of clinical competencies, interpersonal skills, and the leveraging of technological innovation. The proposed concrete educational implications—such as sequential curriculum design, deliberate practice in a metaverse, blended assessment, and faculty development—offer practical guidance for educators. This integration fosters the development of more competent, adaptable physicians prepared for the challenges of the medicine of the future.

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