ENHANCING HEALTHCARE TRAINING THROUGH VIRTUAL AND AUGMENTED REALITY: A META-REVIEW

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Double Blind Peer Review

Citation
D'Ippolito, M., Addimando, L., Lembo, L., & Peluso Cassese, F. (2026). Enhancing healthcare training through virtual and augmented reality: A meta-review. *Italian Journal of Health Education, Sports and Inclusive Didactics. 10*(3).

Doi: https://doi.org/10.32043/gsd.v1i3.1972

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gsdjournal.it
ISSN: 3103-5744

ABSTRACT
The rapid development of Virtual Reality (VR) and Augmented Reality (AR) has increased their use in healthcare education and professional training. This meta-review synthesised systematic reviews published between 2015 and 2025 on the effectiveness of VR and AR in training healthcare professionals. Searches were conducted in PubMed, Scopus, and Google Scholar, and ten reviews met the inclusion criteria. Methodological quality was assessed using AMSTAR 2. Overall, VR and AR supported technical and non-technical skills, including clinical procedures, communication, teamwork, decision-making, empathy, and stress management. They were also associated with greater engagement, knowledge retention, self-confidence, and reduced anxiety.
However, methodological heterogeneity, limited longitudinal evidence, and reliance on self-reported outcomes remain key limitations. Further longitudinal studies are needed to assess long-term learning transfer and clinical impact.

KEYWORDS
Virtual reality; augmented reality; healthcare education; healthcare; training; immersive technologies.

Received 21-09-2026
Accepted 26-10-2026
Published 30-10-2026

1. Introduction

Virtual reality (VR) refers to a computer-generated environment that users can interact with in real-time (Riva et al., 2015), which is characterized by three key features: immersion, sense of presence, and interaction (Sokołowska, 2024). Immersion pertains to the extent to which the sensory input simulates a realistic experience; immersive VR employs head-mounted displays that track the user's movements and dynamically adjust the virtual stimuli accordingly (Slater and Sanchez-Vives, 2014). In contrast, non-immersive VR typically involves the use of multiple screens arranged around the user, providing visual access to the virtual environment (Rahouti et al., 2021). The level of immersion significantly influences the sense of presence, the psychological perception of being physically situated within the virtual environment. Situated between immersive and non-immersive VR is augmented reality (AR), which overlays computer-generated content onto the physical world (Sokołowska, 2024). Finally, interaction refers to the system's capacity to detect user actions and respond with real-time feedback (Sokołowska, 2024).

The integration of immersive technologies such as VR and AR in educational contexts has been shown to enhance active learning, motivation, realism, and perceived relevance (Nischelwitzer et al., 2007). These technologies create interactive and experiential environments that simulate complex or otherwise inaccessible scenarios, thereby promoting spatial understanding, knowledge retention, and contextualized learning through active participation (Makransky and Lilleholt, 2018; Manisha and Gargrish, 2023). Furthermore, VR and AR support personalized learning experiences by offering adaptive feedback and enabling differentiated learning paths, which contribute to the development of self-regulated learning skills. For example, AR facilitates kinesthetic learning

through the manipulation of virtual objects and supports visual learners via dynamic visualizations (Chiusaroli and Arduini, 2023). The pedagogical effectiveness of VR and AR is grounded in cognitive theories such as embodied cognition and experiential learning, which emphasize the role of perception and action in knowledge construction within simulated environments (Dede, 2009). Empirical evidence supports their efficacy across various domains: VR has demonstrated better outcomes compared to traditional instructional methods in science education, language learning, and vocational training (Radianti et al., 2020), while AR has shown particular promise in enhancing learning within Science, Technology, Engineering, and Mathematics (STEM) disciplines (Manisha and Gargrish, 2023). Specifically, in physics education, AR enables interaction with complex three-dimensional models, fostering a deeper conceptual understanding than conventional teaching approaches (Vidak et al., 2024).

These features make VR and AR specifically valuable in educational contexts that benefit from hands-on engagement with learning materials, such as those in healthcare. Traditionally, medical education has relied on students' direct clinical experience under the supervision of more experienced practitioners. However, this model poses several limitations, including risks to patient safety and inconsistencies in clinical experiences (Bradley, 2006). As a result, simulation-based training has become a key component of medical education, enabling repeated practice without involving real patients (Elendu et al., 2024). From this perspective, VR is increasingly recognized as an effective modality in medical education, offering immersive, high-fidelity simulations that closely replicate clinical procedures and environments. Likewise, the integration of AR into healthcare practices offers significant potential to enhance medical education, surgical training, patient rehabilitation, and clinical procedures. VR enables learners to develop technical and cognitive skills through repetitive,

experiential practice in a risk-free context, which is particularly valuable in surgical training, anatomy education, and emergency medicine. Empirical studies have shown that VR-based instruction can lead to superior skill acquisition, reduced error rates, and improved learner engagement compared to traditional didactic or mannequin-based training (Barsom et al., 2016; Maresky et al., 2019). Furthermore, VR platforms provide standardized experiences and real-time feedback, enhancing procedural accuracy and decision-making capabilities. Likewise, AR facilitates anatomy education, enabling medical students to interact with three-dimensional models (Williams et al., 2025), and improves surgical skills, reducing training time and cognitive load (Cao and Cerfolio, 2019). Furthermore, AR applications have proven beneficial in patients' rehabilitation, particularly for individuals with neurological disorders, supporting both physical rehabilitation and patient engagement, motivation and satisfaction (Tang et al., 2020). However, the widespread adoption of VR and AR in medical curricula necessitates rigorous longitudinal research to assess their impact on clinical performance, patient safety, and cost-effectiveness.

Given the rapid expansion of research and applications in this field, there is an increasing need for rigorous evaluation of the methodological quality and educational effectiveness of VR- and AR-based interventions in healthcare. Synthesizing evidence from systematic reviews through structured appraisal tools (e.g., AMSTAR 2) (Shea et al., 2017) allows researchers to identify consistent findings, highlight gaps, and guide future implementation strategies in medical training.

The rapid and ongoing advancements in technology have significantly influenced the development and application of VR and AR, particularly within the educational and healthcare domains. This study aims to provide a structured overview of systematic reviews of the existing evidence on the use of VR and AR technologies, with a specific emphasis on their application in healthcare training. To this end, a systematic literature search was conducted to identify and analyze scientific reviews that summarize key findings regarding the effectiveness of VR and AR in healthcare education.

2. Methods

We conducted a systematic search guided by the following research question: "*What is the impact of AR and VR technologies on skill acquisition in the training of healthcare professionals?",* which was formulated according to the PICO framework (Population, Intervention, Comparison, Outcome; Richardson et al., 1995).

However, the *Comparison* component was intentionally excluded, as the present review was not designed from a clinical trial perspective and did not aim at comparing specific interventions or control conditions. Accordingly, the *Population* comprised healthcare professionals, the *Intervention* referred to the specific AR or VR technologies used in professional training, and the *Outcome* concerned the skills developed or improved through AR- or VR-based training.

The literature search was conducted across PubMed, Scopus, and Google Scholar using the following search terms: [("Virtual Reality") OR ("Augmented Reality") AND ("Training") AND ("Healthcare professionals")]. Searches were restricted to reviews published between 2015 and 2025, written in English, and available in full text. Records retrieved from the three databases were exported to Mendeley (https://www.mendeley.com; last accessed: 09/05/2025) to

merge the search results and remove duplicates. Studies were considered eligible if they: (i) addressed the application of AR and/or VR in the training of healthcare professionals; (ii) were literature reviews; (iii) were published between 2015 and 2025; (iv) were written in English; (v) were available as free full text; and (vi) were published in international peer-reviewed journals.

Following duplicate removal, study selection was conducted in two stages. First, titles and abstracts were screened to exclude records that did not align with the study aim or failed to meet the predefined eligibility criteria. Second, the full texts of the remaining articles were assessed to confirm their eligibility. For each included review, the following information was extracted: (i) the aim of the review; (ii) the skills or professional domains addressed by the VR/AR applications; and (iii) the main findings reported.

The methodological quality of the included systematic reviews was subsequently appraised using the AMSTAR 2 instrument (Shea et al., 2017). AMSTAR 2 enables the critical assessment of systematic reviews including randomized and non-randomized studies of healthcare interventions.

Each review was evaluated across all 16 domains, including the adequacy of the literature search strategy, justification of excluded studies, and assessment of publication bias. The appraisal resulted in an overall confidence rating for each review, providing a structured basis for interpreting the robustness and reliability of the synthesized evidence.

3. Results

Table 1 summarizes the main characteristics of the 10 included systematic reviews, highlighting differences and similarities across aims, target populations, training domains, VR/AR modalities, and main outcomes.

Table 1: Main characteristics of the 10 included systematic reviews

Author (Year)	Aim of Review	VR/AR Modality	Population	Skills/Domain	Main Findings	AMSTAR 2 Rating
Bracq et al. (2019)	VR for non-technical skills	VR immersive simulators	Healthcare professionals	Communication teamwork, decision-making	Improved non-technical skills and user satisfaction	Moderate
Fahl et al. (2023)	Spaced VR training for surgical novices	VR simulators	Surgical trainees	Psychomotor skills	Distributed practice enhances learning	High
Iqbal et al. (2024)	Immersive tech in care and training	VR & AR	Healthcare staff, patients	Technical & emotional skills	Reduced stress, improved adherence	Moderate
Jones et al. (2021)	Dementia care education	VR & AR	Healthcare professionals	Empathy, knowledge	Improved empathy and understandin g	High
Jung (2022)		VR	Hospital staff	Confidence, knowledge retention	Enhanced preparedness and cost-effectiveness	Moderate
Kanschik et al. (2023)	Intensive care training	VR & AR	ICU staff	Procedural, stress management	Better performance, reduced stress	Moderate
Pereira et al. (2020)	Hand rehabilitati on	VR & AR	Patients, therapists	Motor skills, engagement	Improved outcomes and motivation	High
Trevi et al. (2024)	CPR training	VR	Healthcare professionals	Procedural skills	Enhanced realism, memory	Moderate
Tene, Bonilla García, et al. (2024)	Medical physics education	VR & AR	Students	Cognitive learning	No significant improvement	Low
T ene, Vique López, et al. (2024)	Radiation physics training	VR & AR	Students	Engagement, retention	Increased engagement	Low

The initial search identified a total of 50 records across the three selected databases: Scopus (n = 28), PubMed (n = 18), and Google Scholar (n = 4). Following the automated removal of duplicates, 43 unique records were

retained for screening. The first phase of screening, based on titles and abstracts, resulted in the exclusion of 19 records that were not aligned with the inclusion criteria, leaving 24 articles for full-text evaluation. During the second screening phase, the full texts of the remaining articles were assessed for eligibility. Fourteen papers were excluded at this stage, primarily because their focus was not specifically on the application of VR and/or AR technologies in the training of healthcare professionals, but rather on the broader use of digital technologies in healthcare. As a result, 10 articles met all inclusion criteria and were included in the final synthesis (see Figure 1).

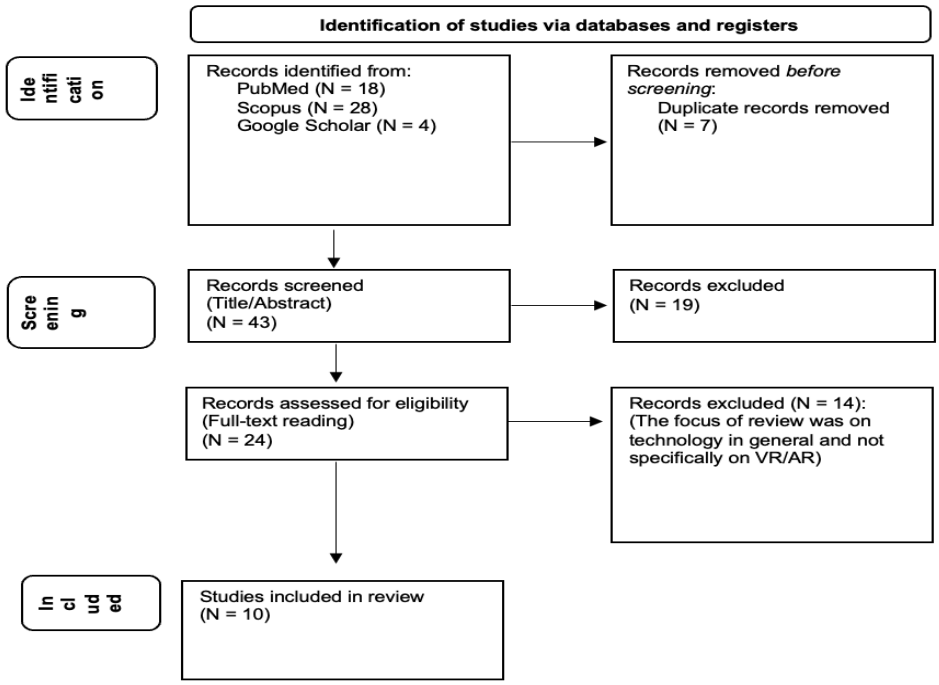


Figure 1: Screening of references included in the overview

3.1. Objectives and scope of the included reviews

The selected studies share a common emphasis on evaluating the impact of VR and AR technologies in enhancing education, training, and skill development within the healthcare sector. Several reviews explored the role of VR and AR in fostering both technical and non-technical competencies across different clinical and educational contexts. For instance, Bracq et al. (2019) analyzed the use of VR for the development of non-technical skills in clinical settings, while Fahl et al. (2023) focused on the acquisition of surgical psychomotor skills, comparing VR-based training with massed practice and examining the effectiveness of different spacing intervals in simulator-based learning. Iqbal et al. (2024) examined the needs and preferences of both healthcare professionals and patients regarding the adoption of immersive technologies, also addressing strategies to improve user acceptance and usability, with a specific focus on patient adherence and treatment outcomes. Similarly, Jones et al. (2021) assessed the effectiveness of VR and AR in dementia-related education and training, highlighting their role in enhancing healthcare professionals' understanding and empathy toward individuals with dementia. Other contributions addressed specialized domains: Jung (2022) explored VR applications in hospital disaster preparedness; Kanschik et al. (2023) investigated the integration of VR and AR in critical care medicine; and Pereira et al. (2020) evaluated their use in supporting hand rehabilitation. Trevi et al. (2024) analyzed the potential of VR in cardiopulmonary resuscitation (CPR) training, emphasizing benefits for both healthcare providers and patients. Lastly, two reviews by Tene and colleagues examined the effectiveness of immersive VR and AR technologies in medical and radiation physics education. Tene, Bonilla García, et al. (2024) focused on immersive educational technologies in medical physics and radiation physics, whereas Tene, Vique López, et al. (2024) evaluated VR and AR in medical education, comparing their effects with traditional instructional approaches or no intervention.

3.2. Skills addressed with the VR/AR technology

The reviewed studies examined a wide array of skills and application domains influenced by VR interventions, spanning both technical and non-technical skillsets. Bracq et al. (2019), for example, investigated the impact of VR on non-technical skills among healthcare professionals, focusing on cognitive and interpersonal abilities such as teamwork, communication, decision-making, leadership, and stress management. Similarly, Iqbal et al. (2024) explored the role of VR in mitigating stress, anxiety, and pain, while Kanschik et al. (2023) emphasized its ability to reduce psychological stress in both patients and healthcare workers, improve adherence to clinical protocols, and enhance performance in high-complexity medical tasks. Jones et al. (2021) assessed the outcomes of VR/AR applications in dementia-related training, specifically evaluating their effects on knowledge acquisition, attitudes toward dementia care, perceived competence and confidence, empathy, and sensitivity to the needs of individuals with dementia. Finally, Jung (2022) explored the use of VR in in-hospital disaster preparedness training, with particular attention to its effectiveness in enhancing participants' confidence and knowledge retention. As for technical skills, Fahl et al. (2023) focused on the role of VR in supporting the acquisition of surgical psychomotor skills, while Pereira et al. (2020) and Trevi et al. (2024) examined its application in hand rehabilitation and cardiopulmonary resuscitation (CPR) training, respectively. Finally, Iqbal et al. (2024) addressed the use of VR in the development of technical competencies within radiology, medical imaging, telemedicine, and invasive clinical procedures.

3.3. Main results

In their systematic review, Bracq et al. (2019) identified teamwork, communication, and situational awareness as the non-technical skills most frequently addressed through VR-based training in healthcare. They also noted that most of the included studies focused on the assessment of VR simulators' usability and acceptability, whereas only a limited subset directly evaluated their impact on skill acquisition and improvement. Fahl et al. (2023) showed that distributing VR training over multiple sessions leads to better development of psychomotor skills and improved surgical performance compared to single-day training. Iqbal et al. (2024) reported that VR and AR enhance both patient care and medical training by offering immersive, interactive environments; their findings included reductions in stress, anxiety, and acute pain via the use of immersive games and video-based distractions. Moreover, VR and AR contributed to post-intensive care rehabilitation, reduced procedural discomfort, and improved outcomes in radiology and surgery through enhanced 3D visualization, surgical accuracy, patient safety, and clinical efficiency. Jones et al. (2021) emphasized the role of immersive technologies in improving knowledge, attitudes, empathy, and sensitivity among healthcare professionals, particularly in dementia care, while Jung (2022) highlighted three key benefits of VR-based training: the ability to realistically simulate clinical and disaster scenarios, increased learner confidence and knowledge retention, and cost-effectiveness in program implementation. According to Kanschik et al. (2023), VR and AR can support intensive care training by facilitating complex procedural planning and execution. These technologies were also associated with reduced stress and pain during invasive procedures, improved communication with patients' families, and enhanced rehabilitation outcomes. Pereira et al. (2020) found that VR/AR interventions led to improved hand rehabilitation outcomes, as confirmed by randomized controlled trials. They also identified motivational factors that promoted adherence, including real-

time feedback, task challenge, and adaptive difficulty levels. Tene et al. (2024b) did not observe a statistically significant improvement in educational outcomes associated with VR use. However, Tene et al. (2024a) reported increased learner performance and engagement when VR/AR technologies were integrated into training programs. Similarly, Trevi et al. (2024) found that healthcare professionals perceived virtual environments as realistic and engaging, with positive effects on procedural memory, particularly in the use of defibrillators and execution of chest compressions. However, they also identified limitations, such as limited decision-making opportunities, reduced team interaction, psychological strain, and challenges related to demanding virtual scenarios. Notably, their review included a study (Katz et al., 2020) indicating a more favorable cost–benefit ratio for VR-based CPR training compared to traditional methods.

4. Study limitations

The findings of the present overview should be interpreted in light of several methodological limitations.

First, the final sample comprised a relatively small number of systematic reviews (n = 10), which may limit the generalizability of the findings. This limitation is particularly relevant in a rapidly evolving field, in which new technologies and applications are continuously emerging and recent or non-indexed studies may therefore have been overlooked. Second, substantial methodological heterogeneity was observed across the included reviews. Differences in study design, population characteristics, technological platforms, training protocols, and outcome measures hinder direct comparisons and limit the feasibility of quantitative synthesis. Moreover, the lack of standardized

assessment tools and outcome measures contributed to variability in the reported findings.

Third, several reviews placed considerable emphasis on usability, feasibility, and user satisfaction, while providing limited evidence on long-term learning outcomes and the transfer of acquired skills to real-world clinical settings. Although these dimensions are relevant, this focus may limit a more comprehensive evaluation of the sustained educational effectiveness of VR- and AR-based interventions. In particular, the scarcity of longitudinal studies restricts the assessment of their long-term impact on professional performance, decision-making, and patient care. Finally, several included reviews did not clearly distinguish between interventions targeting healthcare professionals, students, and general users, potentially introducing ambiguity in the interpretation of findings specifically related to professional training. These limitations underscore the need for future research to adopt more rigorous and standardized methodologies, incorporate long-term outcome measures, and assess more directly the effectiveness and transferability of VR- and AR-based training in real-world clinical environments. Furthermore, the application of the AMSTAR 2 criteria revealed that most reviews were characterized by moderate methodological quality, with recurring limitations particularly in the registration of a priori protocols and comprehensive risk-of-bias assessment. Strengthening methodological and reporting standards will therefore be essential to improve the reliability and transparency of future systematic reviews in this field.

5. Conclusions

This overview highlights the increasing relevance of VR and AR within healthcare education and professional training, with the available evidence

suggesting potential benefits for both technical and non-technical skills development.

VR- and AR-based interventions have been associated with improvements in decision-making, communication, teamwork, leadership, and stress management (Bracq et al., 2019; Iqbal et al., 2024; Kanschik et al., 2023), as well as with the development of technical skills in areas such as surgery, rehabilitation, radiology, telemedicine, and cardiopulmonary resuscitation (Fahl et al., 2023; Pereira et al., 2020; Trevi et al., 2024). Immersive technologies have also been associated with lower levels of anxiety, pain, and stress among both patients and healthcare professionals. (Iqbal et al., 2024; Kanschik et al., 2023). In emergency and high-complexity clinical contexts, VR-based training has shown potential to enhance confidence, knowledge acquisition, and procedural performance (Jung, 2022; Kanschik et al., 2023). In addition, VR and AR may contribute to the development of empathy and more informed attitudes towards vulnerable patient populations, including individuals with dementia (Jones et al., 2021).

However, the evidence remains heterogeneous: while some reviews did not identify statistically significant improvements in educational outcomes (Tene et al., 2024b), others reported increased learner engagement and performance following the integration of immersive technologies into training programmes (Tene et al., 2024a). Potential limitations, including restricted opportunities for decision-making and team interaction in some virtual environments, should also be considered (Trevi et al., 2024). Nevertheless, available evidence suggests that VR and AR may represent valuable complementary tools within healthcare training, with some evidence also supporting their potential cost-effectiveness (Katz et al., 2020).

Future research should adopt methodologically robust longitudinal designs to establish whether the benefits observed in simulated environments are

maintained over time and translate into measurable improvements in real-world clinical performance and patient-related outcomes.

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