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## Literature Review

## Can wearable electronic devices bring a new paradigm to simulations in healthcare education? A scoping review

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## ABSTRACT

**Objectives:** This study aimed to review the use of wearable electronic devices as a support tool in the teaching-learning process for healthcare professionals.

**Design:** A scoping review was conducted to analyze existing literature on the role of wearables in medical and nursing education.

**Data Sources:** A comprehensive search was performed in PubMed, Scopus, and Web of Science databases between September and November 2024.

**Review Methods:** Peer-reviewed, English-language articles published between 2014 and 2024 were included. Articles were screened for relevance, and a total of 20 studies were selected for final review based on predefined inclusion criteria.

**Results:** The findings suggest that wearables enhance student motivation and learning outcomes by providing real-time feedback and objective assessments. However, despite these advantages, challenges such as implementation barriers and validation concerns remain.

**Conclusions:** Wearable technology shows promise in healthcare education, but further research is necessary to establish its effectiveness in skills development and long-term training models.

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Technology integration is increasingly influencing healthcare education, enhancing training quality and, consequently, patient care and safety (Alsaleh, 2024; Romli et al., 2020). Kulju et al. (2024) emphasize the need to embed technology in curricula to develop digital competencies and prepare students for a digitalized healthcare environment.

Clinical simulation has been a staple in healthcare education to improve professional competence (Elendu et al., 2024). Recently, technologies like virtual and augmented reality have enhanced the development of technical and non-technical skills, fostering critical thinking and clinical decision-making in complex healthcare settings (Halimah et al., 2024; Stenseth et al., 2022).

The convergence of artificial intelligence (AI) and conventional electronic technologies has fostered the emergence of a new class of intelligent systems known as wearables. These systems are increasingly influencing both the education and training of healthcare professionals, as well as the broader delivery of healthcare services (Shi et al., 2020). Wearables refer to electronic devices designed to be

worn on the body, and are capable of collecting, processing, and transmitting data in real time (Lu et al., 2024).

Wearables are increasingly employed in healthcare settings to monitor physiological parameters thereby providing valuable real-time data that can inform personalized clinical interventions (Adeghe et al., 2024). In the context of medical education, these devices function as pedagogical tools, enabling healthcare students to engage in the repeated practice, controlled environment without posing any risk to patients (Araújo et al., 2024).

In healthcare education and training, wearables are applied in three main ways. First, they monitor physiological parameters, offering insight into learners' states—such as stress—during practice (Jenks et al., 2020). Second, they record movement patterns to evaluate the development of technical skills (Zulbaran-Rojas et al., 2021). Third, they support repetitive practice through virtual reality, enhancing skill acquisition without endangering patients (Jung & Park, 2022). This review examines all three uses to provide a comprehensive perspective on the educational value of wearables.

Although the functions attributed to wearables vary widely, the terminology used to describe them remains largely consistent across the literature. This uniform use of the term wearable can obscure important pedagogical differences among devices. Previous reviews

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often adopt this broad approach, potentially overlooking key distinctions. For example, Araujo et al. (2024) focused their systematic review on nursing education, addressing a narrower professional group and a more limited range of devices.

In contrast, this review addresses a significant gap by disaggregating the term wearable across both medical and nursing education, offering a comprehensive mapping of their applications in diverse educational contexts. This inclusive approach avoids overlooking relevant use cases and proposes a novel framework to understand how different device types uniquely support simulation-based learning, contributing to a more pedagogically grounded perspective largely absent from previous reviews.

## Methods

A scoping review was chosen as the methodology. This methodological approach synthesizes evidence, enabling researchers to explore the scope and breadth of literature on a specific topic (Hadie, 2024). It is designed to systematically map the extent, range, and nature of relevant research within a particular field of interest, providing a comprehensive overview and identifying key themes, gaps, and areas for further investigation (Arksey & O'Malley, 2005). Within this methodology, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) were followed for this review (Page et al., 2021).

The aim of this review was to explore the role of wearables in healthcare education, particularly in relation to their potential to inform new paradigms or theoretical frameworks for simulation-based training. To address this aim, four specific objectives were established: (1) to examine the terminology used within the educational field to refer to wearables and facilitate access to prior research; (2) to identify the types of wearables currently available and the data they provide; (3) to analyze the impact of these technologies on the training of healthcare professionals; and (4) to assess their potential to transform teaching and learning processes.

Accordingly, four guiding research questions were formulated: (1) What terminology is used to describe wearables in healthcare education? (2) What types of wearables are available for educational purposes, and what kind of data do they generate? (3) How does the use of wearables influence the training experiences of healthcare professionals? and (4) Can wearables contribute to the development of new theoretical frameworks in healthcare education?

The structured approach facilitated a comprehensive examination of the current landscape, highlighting the potential of wearables to enhance traditional healthcare training models. Consequently, the scoping review methodology was identified as the most suitable to address the study's aims.

### Identification of Relevant Studies

A systematic search of literature published from 2014 onwards was conducted in PubMed, Scopus, and Web of Science to identify relevant studies. These databases were selected for their comprehensive and reputable coverage of the topic, ensuring both the efficiency of the search process and the quality of the studies included.

This scoping review excluded grey literature to prioritize peer-reviewed sources that ensure methodological consistency and validated results. While grey literature can offer useful insights, its inclusion was avoided due to the lack of peer review, methodological variability, and challenges in retrieval.

As previously noted, various terms are used in the literature to refer to wearables. To address this terminological variability, the researchers employed the multilingual thesaurus DeCS/MeSH (Health Sciences Descriptors/Medical Subject Headings), developed by BIREME, as a standardized vocabulary for indexing scientific

materials, including journal articles, books, conference proceedings, technical reports, and other publications. This thesaurus also facilitates the search and retrieval of scientific literature from sources available in the Virtual Health Library. The literature search was conducted using DeCS/MeSH terms combined with Boolean operators to optimize the retrieval of relevant studies. Key search terms included “wearable electronic devices,” “education, medical,” and “education, nursing.”

The initial search yielded 268 articles. After exporting the results to Microsoft Excel 2021 (version 16.91), 34 duplicates were identified and removed, leaving 234 unique records. Titles and abstracts of these records were then screened, resulting in the exclusion of 156 articles that did not align with the predefined search criteria. Of the remaining 78 articles, 52 were excluded because they did not focus on healthcare professionals, 3 were excluded for not addressing wearables, and 3 were excluded due to the unavailability of their full texts. Consequently, full-text analysis was conducted on 20 articles. Figure 1 illustrates the flowchart depicting this selection process. Ultimately, 20 articles were included as they met the inclusion criteria and aligned with the research objectives.

### Data Charting Process

The lead author systematically collected data on study characteristics, methodology, findings, and implications using a standardized extraction form developed for this review. Specific data categories included study design, sample size, participant characteristics, type and function of the wearable used, outcome measures, and main findings. Two reviewers independently carried out the data extraction process. Any discrepancies were discussed and resolved by consensus, or with the involvement of a third reviewer when necessary.

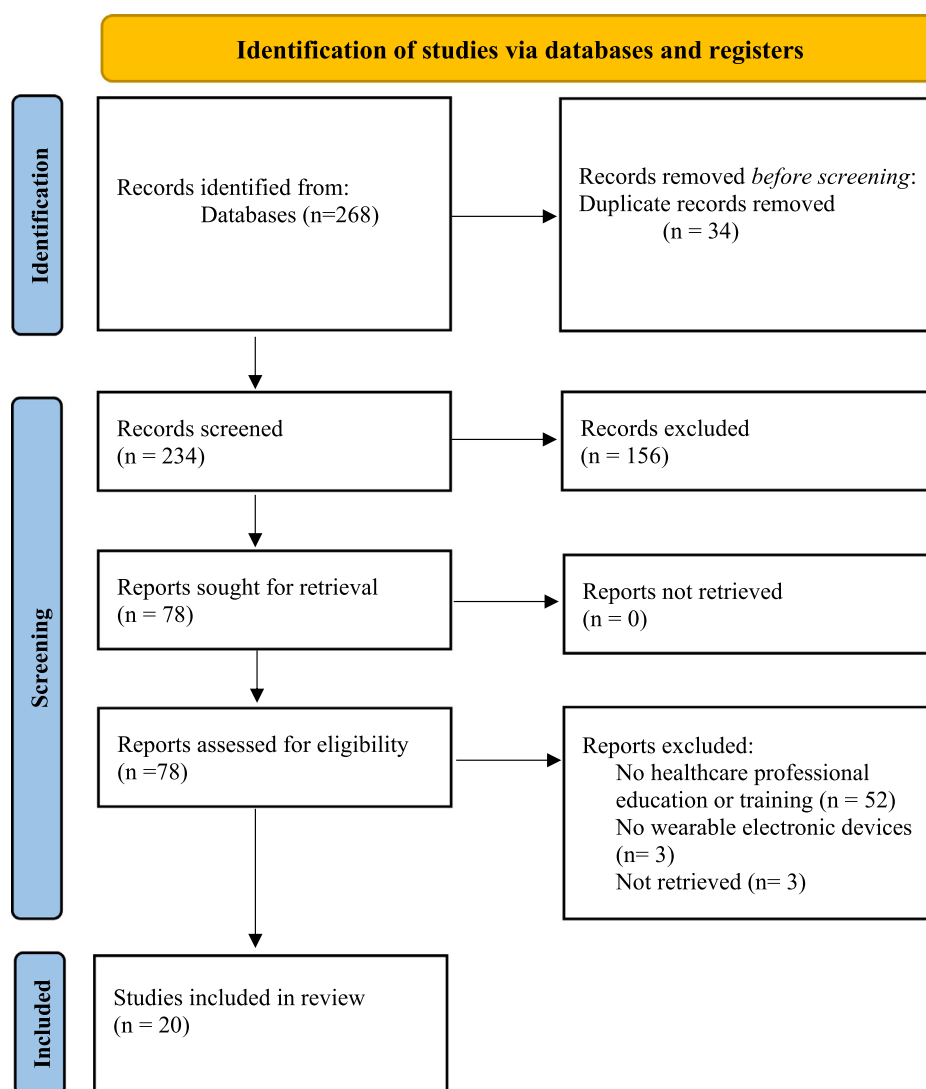
The final articles included in this review were assessed for quality using the GRADE (Grading of Recommendations, Assessment, Development, and Evaluation) system (Goldet & Howick, 2013). This framework evaluates the quality of evidence based on five criteria: risk of bias in randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Each domain was rated as low risk, some concerns, or high risk of bias. The overall certainty of the evidence was then categorized as high, moderate, low, or very low. However, the methodological quality of the studies did not influence inclusion or exclusion decisions, as the goal of a scoping review is to map the breadth and scope of available evidence (Peterson et al., 2017). A detailed summary of the GRADE assessment results is provided in Supplementary File 1.

## Results

### Study Characteristics

No statistical analysis was conducted; instead, the results of the 20 included studies are summarized in Table 1, which outlines their key characteristics and relevant information. The studies were conducted across various countries and involved a wide range of sample sizes, from 7 to 284 participants. This variation likely reflects differences in research objectives, methodological approaches, and available resources, contributing to the observed heterogeneity.

The populations studied can be categorized into several groups: nursing students, medical students, university faculty, residents from various medical specialties, specialist nurses, attending physicians, one multidisciplinary team, and combinations of two or more of these categories.



**Figure 1.** Study selection process according to the PRISMA 2020 flow diagram. Adapted from Page et al. (2021), PRISMA 2020 flow diagram.

### Results Synthesis

In response to the research question “What terminology is used to refer to wearables?”, the reviewed studies employed a variety of terms to describe these devices. The term wearable device was the most frequently used, appearing in seven of the twenty analyzed articles (Birbara et al., 2020; Dickerson et al., 2019; Jenks et al., 2020; Kim et al., 2021; Landry et al., 2019; Lu et al., 2019; Silva et al., 2020). This was followed by wearable sensor, used in five studies (Corvetto et al., 2017; Perrone et al., 2020; Rose et al., 2017; Ross et al., 2019; Zulbaran-Rojas et al., 2021). The term wearable technology appeared in four articles (Currie et al., 2019; Valles et al., 2022; Vergara-Escudero et al., 2024; Zhao & Cong, 2019), while wearable displays was used by two authors (Jung & Park, 2022; Kim et al., 2023). Lastly, two studies referred to these technologies by naming the specific device under investigation (Logishetty et al., 2019; Reed et al., 2023).

The review identified a diverse range of wearables used in different educational contexts. To enable systematic analysis, these devices were organized into categories according to their form, function, and technological features. Table 2 presents a structured classification of the wearables identified, grouping products with similar core functions under each category, and specifying the devices as commercial brands. This approach enhances clarity and consistency in data

presentation, and facilitates comparative analysis and the identification of patterns and trends across studies.

In response to the research question “What types of wearables are available for use in the training of healthcare professionals, and what data can be obtained through them?”, the reviewed articles were classified into four functional categories based on the primary type of data collected and their educational application: (1) Image acquisition, as defined by Dickerson et al., as the process of capturing visual data, image or videos, that can later be analyzed for educational purposes, such as enhancing skills and knowledge (Dickerson et al., 2019; Jung & Park, 2022; Kim et al., 2021; Landry et al., 2019; Logishetty et al., 2019; Reed et al., 2023; Vergara-Escudero et al., 2024; Zhao & Cong, 2019). (2) Evaluating perceptions referring to the process of using wearables to assess and analyze how users perceive their experiences, interactions or environments during training or educational activities (Kim et al., 2023). (3) Collecting motion data to obtain movement metrics, such as speed, trajectory, or the number of movements, which help classify participants by their level of experience and identify patterns useful for assessing technical skills (Corvetto et al., 2017; Lu et al., 2019; Perrone et al., 2020; Rose et al., 2017; Valles et al., 2022; Zulbaran-Rojas et al., 2021). (4) Psychophysiological measurements according to Jenks et al. are the collection of data related to individuals’ physical and emotional responses to

**Table 1**  
Study characteristics.

Authors (Year)	Country	Aim	Methods	Type of wearable	Participants/Population	Findings	Implications for healthcare professionals	Quality appraisal
Birbara et al. (2020)	Australia	To compare perceptions of highly immersive and less immersive virtual learning resource (VLR) deliveries among anatomy students and tutors	Pilot study	AVIE stereoscopic immersive interactive visualization	75 medical university students and 6 anatomy tutors	Both methods were engaging; however, students preferred the stereoscopic version for understanding and exploring detailed anatomical structures, whereas tutors favored the desktop version	Highly immersive VLRs have the potential to transform healthcare education and training, making it more effective and better aligned with the practical needs of healthcare professionals	Very low
Corvetto et al. (2017)	Chile	To validate the hand motion analysis of Imperial College Surgical Assessment Device (ICSAD) in a simulated model of spinal anesthesia	Quantitative experimental study	ICSAD hand motion device	10 anesthesiologists' residents (novice), 10 residents (intermediates) and 10 attending anesthesiologists (experts)	Global Rating Scale scores were significantly higher among experts. Regarding total path length, number of movements, and procedural time measured with ICSAD, significant differences were observed between all groups	The ICSAD hand motion device has the potential to provide objective data for the design and improvement of simulation-based training programs with reliable and measurable goals	Moderate
Currie et al. (2019)	Ireland	To explore the use of wearables to develop metrics that can automatically assess operator and procedural performance during cardiac catheterization	Quantitative observational study	SMI eye tracking glasses and Empatica's E4 wristband	7 expert interventional cardiologist and 7 novices	Experts demonstrated greater attentional capacity, spending more time focused on display screens than novices. Enhanced tracking of unrelated objects was associated with fewer errors, suggesting that higher attentional capacity contributes to improved performance	The SMI eye-tracking glasses and Empatica's E4 device have the potential to offer real-time, objective assessments of clinical performance thereby enhancing training and improve patient outcomes	Very low
Dickerson et al. (2019)	United States of America	To assess the feasibility and effectiveness of using Google Glass to enhance the surgical skills education of orthopedic surgery residents	Partially blinded randomized control trial	Google Glass smart glasses	42 orthopedic surgery residents	Although no statistically significant differences were found between the two groups, qualitative analysis revealed the participants perceived the video coaching as beneficial	The Google Glass holds significant potential as an innovative educational tool for healthcare professionals, particularly in the context of technical skills training	Very low
Jenks et al. (2020)	United States of America	To assess stress levels in emergency medicine residents by measuring heart rate using a wristband, a wearable physiological monitor	Blinded observational study	Empatica's E4 wristband	23 emergency medicine residents	Continuous heart rate monitoring during standard critical care shifts revealed marked elevations indicative of episodic tachycardia, which have been explored as potential physiological markers of acute stress levels in clinical settings	The Empatica's E4 device has the potential to enable continuous monitoring of vital signs such as heart rate to support development of stress detection and management programs that enhance professional performance	Very low
Jung & Park (2022)	South Korea	To develop a head-mounted display-based virtual reality nursing program (HMF-VRP) in chemport insertion and evaluate its effects	Quasi-experimental study	Head-mounted display with virtual reality	60 nursing students	The experimental group that underwent HMD-VRP demonstrated significantly greater post-intervention improvements in operating nursing knowledge, learning attitude, and satisfaction compared to the control group	HMD-based virtual reality platforms have the potential to improve nursing students' knowledge, learning attitudes, satisfaction, and engagement during surgical training	Very low

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Table 1 (Continued)

Authors (Year)	Country	Aim	Methods	Type of wearable	Participants/Population	Findings	Implications for healthcare professionals	Quality appraisal
Kim et al. (2021)	South Korea	To develop a smart glass-based nursing training program and evaluate its usability and feasibility for the implementation of self-practice among nursing students	Usability and feasibility study	Vuzix smart glasses	30 nursing students	Smart glass–assisted self-practice of nursing skills was perceived as helpful, convenient, and engaging. Participants also reported a significant improvement in their perceived competency	The Vuzix smart glasses have the potential to facilitate self-directed practice by delivering timely information at learners' individual pace	Very low
Kim et al. (2023)	South Korea	To evaluate the psychometric properties of two tools assessing nursing students' attitudes toward wearable display technology	Validity and reliability study	Smart glasses	284 nursing students	Exploratory factor analysis identified three factors comprising thirteen items related to positive attitudes. The instrument demonstrated good internal consistency	Smart glasses possess considerable potential to advance nursing education and facilitate the acquisition of essential clinical competencies.	Very low
Landry et al. (2019)	Canada	To evaluate whether the use of video glasses improves the overall learning experience for trainees observing tonsillectomy and adenoidectomy	Single center randomized prospective trial	LED DayLite NanoCam HD video glasses	12 medical students and 11 surgical residents	The overall learning experience, ability to identify anatomical structures, and the ease of following surgical steps were rated significantly higher by participants using video glasses	The DayLite video glasses have the potential to serve as a realistic and effective learning tool for procedures with limited fields of view, benefiting learners across all levels of training	Low
Logishetty et al. (2019)	United Kingdom	To assess whether an augmented reality headset could enhance novices' accuracy in acetabular positioning compared to traditional training.	Randomized simulation trial	Microsoft HoloLens augmented reality headset	24 medical students applying to surgery residency programs	Microsoft HoloLens has been shown to be as effective as traditional training methods in improving the accuracy of acetabular component positioning during simulated total hip arthroplasty	The Microsoft HoloLens augmented reality headset has the potential to complement traditional surgical training methods by enabling skill development without direct expert supervision	Low
Lu et al. (2019)	Taiwan	To evaluate the effectiveness of a smartwatch with real-time feedback in enhancing CPR quality among healthcare professionals	Randomized controlled simulation study	ASUS ZenWatch 2 (Model WI501Q) smartwatch	80 health professionals of Emergency department	The use of ASUS ZenWatch 2 has been shown to significantly enhance the delivery of high-quality CPR, particularly by improving compression depth accuracy and adherence to ventilation guidelines	The ASUS ZenWatch2 smartwatch which provides real-time feedback has the potential to improve CPR training and the quality of emergency care delivered by healthcare professionals	Low
Perrone et al. (2020)	United States of America	To explore whether differences in motion data during a simulated laparoscopic ventral hernia (LVH) repair could be used to stratify top and lower tier performers	Pilot study	TrakSTAR Model 180 motion-tracking device	94 surgical residents	Top performers received higher product quality scores, with raters identifying clear performance patterns. Motion plots were aligned with procedural segments to support detailed analysis	Motion-tracking data from the TrakSTAR model 180 has the potential to identify deviations from best practices, thereby guiding targeted improvements in surgical training	Very low
Reed et al. (2023)	United States of America	To explore the use of smart glasses in providing educators with a first-person learner perspective during Objective Structured Teaching Exercises (OSTE) for faculty development	Descriptive study	Hereta Spy Camera smart glasses	17 assistant professors from 12 different medical specialties	Incorporating Smart Glasses into OSTEs provides constructive feedback on body language, eye contact, and vocal tone, without causing distraction to the participant	The Hetera Spy camera, when incorporated into teaching exercises, has the potential to enhance feedback quality and support faculty development	Very low

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Table 1 (Continued)

Authors (Year)	Country	Aim	Methods	Type of wearable	Participants/Population	Findings	Implications for healthcare professionals	Quality appraisal
Rose et al. (2017)	United States of America	To develop a model using inertial sensors to assess the performance of orthopedic residents while performing a diagnostic knee arthroscopy	Experimental research study	Opal wearable inertial sensors	5 novice resident surgeons, 5 intermediates resident and 4 fellowship-trained surgeons (experts)	Wearable inertial sensors have proven effective in measuring joint kinematics and offer valuable insights into the skill levels of individuals performing arthroscopic procedures	Opal inertial sensors, integrated into surgical training programs, have the potential to significantly improve skill acquisition and surgical outcomes	Very low
Ross et al. (2019)	Canada	To develop a novel framework for adaptive simulation that can dynamically adjust the complexity of the simulation based on the participant's level of expertise	Quantitative experimental study	Microsoft HoloLens smart glasses and Shimmer3 wearable sensors	5 emergency medicine physicians and 5 medical students (4-year)	The extracted features demonstrated a clear distinction between expert and novice trauma responders, with the combined use of electrocardiogram and galvanic skin response features showing the greatest discriminatory capability	The Microsoft HoloLens combined with Shimmer3 sensors has the potential to tailor cognitive load and maximize educational effectiveness through adaptive simulation paradigms that autonomously classify participants' expertise levels	Very low
Silva et al. (2020)	Portugal	To assess the stress levels of medical students and predict burnout by using wearable devices and machine learning techniques	Non-experimental study	Microsoft Band 2	83 medical students	Significant differences in heart rate and heart rate variability variables were observed between baseline and examination conditions. Among the models evaluated, the neural network demonstrated the best fit	The Microsoft Band 2 has the potential to support the identification, measurement, and management of stress in daily healthcare practice	Very low
Valles et al. (2022)	Australia	To validate a mixed reality (MR) headset with hand and eye-tracking as an objective assessment tool and identify metrics that reliably differentiate skill levels in a simulated open surgery task	Prospective observational study	Microsoft HoloLens mixed reality headset	18 medical students (novices), 8 pediatric surgeons (intermediates) and 8 pediatric consultant surgeons (experts)	Participants completed four simulated surgical tasks. Significant differences in task speed were observed, with experts exhibiting more economical movements, shorter path lengths, and faster completion times compared to novices	The Microsoft HoloLens MR headsets have the potential to serve as valid supplementary tools for assessing surgical performance in simulation-based settings	Very low
Vergara-Escudero et al. (2024)	United States of America	To explore the use of wearable video-recording technology to measure the timing of discrete events during perioperative central venous catheter (CVC) placements	Prospective observational Single-center, study	Tobii Pro Glasses3 head-mounted device	13 clinical anesthesia residents, 1 cardiothoracic anesthesia resident and 4 attending anesthesiologists	Practitioners with greater experience exhibited more consistent performance, characterized by reduced variability across repeated trials	The Tobii Pro Glasses 3 HMD has the potential to identify inefficiencies and inform the development of interventions that enhance trainee performance and patient safety	Very low
Zhao & Cong (2019)	China	To evaluate the feasibility of combining wearable technology (WT) with Problem and Scripting based learning in training of novice orthopedic nurses	Randomized controlled trial	Google Glass smart glasses	20 operating room (OR) post-graduate-year-1 nurses	The combined use of WT and Problem-Solving-Based Learning has proven to be a more effective training approach for novice orthopedic operating room nurses compared to conventional methods	The Google Glass, when combined with PSBL programs, has the potential to transform nursing education and healthcare delivery by cultivating skilled and confident professionals	Low

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Table 1 (Continued)

Authors (Year)	Country	Aim	Methods	Type of wearable	Participants/Population	Findings	Implications for healthcare professionals	Quality appraisal
Zulbaran-Rojas et al. (2021)	United States of America	To evaluate the kinematics of surgical proficiency and differentiate between novice and expert surgeons by using a flexible wearable sensor during a vascular anastomosis task	Quantitative observational study	BioStampRC™ flexible wearable sensor	12 expert surgeons and 8 novice surgeons categorized by modified objective structured assessment of technical skills (mOSATS)	Experts completed tasks faster and with better hand coordination than novices. Their mOSATS scores negatively correlated with task time and hand movements, indicating greater efficiency with higher proficiency	The BioStampRC™ has the potential to provide objective metrics for assessing and improving surgical training processes, as well as distinguishing professionals' levels of expertise based on task performance	Very low

assess how healthcare professionals react to stressful or emotional situations and the influence on learning specific tasks (Currie et al., 2019; Jenks et al., 2020; Ross et al., 2019; Silva et al., 2020).

When addressing the third research question How does the use of wearables by healthcare professionals influence their training, considering both positive and negative aspects?, highlighting the positive aspects of incorporating wearables into teaching methodologies according to the extracted data, the following categories were extracted: (1) immediate feedback, (2) the overall satisfaction of users who perceive wearables as a more engaging learning tool compared to traditional approaches, (3) collection of metrics to facilitate more objective evaluations, (4) the ability to classify students or professionals based on their level of expertise, and (5) the enhancement of understanding and skills in specific learning contexts and (6) real-time monitoring capabilities.

The categories extracted to classify the negative points were the following: (1) technical issues such as device calibration or connectivity, (2) high initial economic and time investment for purchasing materials and training instructors, (3) physical discomfort such as headaches and dizziness, (4) distraction, (5) dependency on technology referring to an excessive reliance on digital tools and technological devices in the learning process, which may hinder skill development and adaptability when these resources are unavailable, (6) cognitive overload, (7) data handling to ensure privacy, (8) tendency for positive perceptions among students due to working with an innovative method.

Regarding the last research question, Can the use of wearables introduce a new framework or paradigm for training models for health professionals? it was formulated to identify whether there are educational tools that could lead to a shift from traditional learning methods to more technologically advanced training for healthcare professionals. In considering whether the use of wearables could represent a new paradigm or framework for clinical simulations in medical and nursing education, although only six articles explicitly mention the term paradigm or framework (Corvetto et al., 2017; Reed et al., 2023; Rose et al., 2017; Ross et al., 2019; Valles et al., 2022), all included studies aimed to introduce educational tools that support a shift toward more advanced learning models.

## Discussion

This review was designed to critically analyze the role of wearables in supporting teaching and learning processes among healthcare professionals. One of the core findings is the importance of differentiating among types of wearables, as each presents distinct educational functionalities and limitations. While often grouped under the general term wearables, these devices vary widely in purpose, sensor capabilities, and pedagogical impact. Therefore, a nuanced understanding of each type's contribution is vital for their effective integration into simulation-based education.

Smart glasses (Birbara et al., 2020; Dickerson et al., 2019; Jung & Park, 2022; Kim et al., 2023; Kim et al., 2021; Landry et al., 2019; Logishetty et al., 2019; Reed et al., 2023; Ross et al., 2019; Valles et al., 2022; Vergara-Escudero et al., 2024; Zhao & Cong, 2019) offer immersive experiences that significantly enhance the learning environment. These tools allow learners to engage in first-person simulations that replicate clinical environments with high fidelity. Their main educational advantage lies in their capacity to support real-time procedural guidance, visual overlays and remote mentorship via live-streaming. These features can be particularly valuable in surgical training, emergency response simulations, and interprofessional education, where real-time situational awareness and multitasking are critical.

Motion-tracking devices (Corvetto et al., 2017; Perrone et al., 2020; Rose et al., 2017) bring an additional analytical layer to skills-based training by capturing precise body movements and motion

**Table 2**  
Wearable's classification.

Wearable category	Functional description	Devices*	Authors (Year)
Smart glasses	Wearables designed to capture and process the user's physical environment while superimposing virtual elements, thereby enhancing perception and interaction through augmented reality technologies (Zuidhof et al., 2021).	Microsoft HoloLens Google Glass AVIE immersive visualization LED DayLite Nanocam HD Samsung Gear VR Mobile Head-mounted displays Hereta Spy Camera Glasses Tobii Pro Glasses 3 Vuzix Imperial College Surgical Assessment device	Logishetty et al., 2019; Ross et al., 2019; Valles et al., 2022 Dickerson et al., 2019; Kim et al., 2023; Zhao & Cong, 2019 Birbara et al., 2020 Landry et al., 2019 Jung & Park, 2022 Reed et al., 2023 Vergara-Escudero et al., 2024 Kim et al., 2021 Corvetto et al., 2017 Perrone et al., 2020 Rose et al., 2017
Motion tracking devices	Wearables designed to reconstruct three-dimensional representations of human movement using sensor-generated data, enabling advanced applications in gesture recognition, spatial interaction, and movement analysis (Song et al., 2021).	TrakSTAR model 180 Opal sensors, APDM	
Smart bands	Wearables designed to be worn on the body to monitor health-related metrics, track physical activity, and provide real-time feedback for personal health management and behavioral monitoring (Currie et al., 2019).	Empatica's E4 Microsoft band 2	Currie et al., 2019; Jenks et al., 2020 Silva et al., 2020
Wearable sensors	Wearables designed to collect biometric and physiological data in real time, supporting continuous monitoring for clinical, research, or personal wellness purposes (Rose et al., 2019).	BioStampRC™ Shimmer 3	Zulbaran-Rojas et al., 2021 Ross et al., 2019
Smart watches	Wearables designed to monitor physiological parameters and interface seamlessly with mobile applications, facilitating real-time data collection, analysis, and user interaction (Lu et al., 2019).	ASUS ZenWatch 2 (Model WI501Q)	Lu et al., 2019

\* Commercial brands.

trajectories during clinical procedures. These tools are increasingly integrated into surgical skills labs, where they record detailed hand movements in tasks such as suturing or laparoscopic navigation. The resulting performance data—such as movement smoothness and task completion time—can be visualized through performance maps to correct suboptimal techniques, reduce inefficiencies, and reinforce muscle memory. Furthermore, these systems are particularly valuable when used with structured assessment tools, as they enable standardized, objective evaluation across learners and support longitudinal tracking of individual skill acquisition over time.

Smart bands (Currie et al., 2019; Jenks et al., 2020; Silva et al., 2020) and smart watches (Lu et al., 2019), while less visually immersive than other devices, play a critical role in capturing psychophysiological data that reflect learners' emotional and cognitive states. By continuously monitoring parameters such as heart rate variability, these wearables offer real-time insights into how individuals respond to stress and cognitive load during training. This information is especially valuable in high-fidelity, stress-based simulation scenarios. For example, in prehospital care simulations, smart bands can issue alerts when a participant's stress levels surpass a predefined threshold, prompting real-time scenario adjustments or the introduction of guided breathing exercises. These applications support a broader pedagogical focus on resilience, well-being, and adaptive learning, allowing instructors to tailor instructional pacing and collaborative strategies based on the learners' psychophysiological profiles.

Wearable sensors (Ross et al., 2019; Zulbaran-Rojas et al., 2021) are highly versatile, capable of collecting multimodal physiological signals such as ECG, EMG, and galvanic skin response. These data streams offer a rich understanding of learners' physical responses to different training scenarios. In high-stakes or ethically complex simulations—such as trauma care, end-of-life discussions, or team-based

crisis management—such insights help educators assess not only technical performance but also learner readiness and emotional regulation. This positions wearable sensors as critical components in the design of more holistic training environments.

The implications of these findings extend beyond the selection of technologies; they call for a systematic rethinking of how wearable data can be integrated into curricula and pedagogical models. Currently, there is a notable absence of explicit conceptual frameworks guiding the educational use of wearables. Future research should aim to fill this gap by developing models that combine learning theory, physiological data interpretation, and instructional design. For example, integrating feedback derived from wearables into constructivist or experiential learning models could support more adaptive and learner-centered simulation strategies.

In terms of curricular integration, it is crucial to align the capabilities of specific devices with relevant competencies. Smartwatches might be integrated into basic life support courses to provide real-time feedback on compression quality, while motion trackers could be employed in surgical rotations to assess laparoscopic precision. Smart glasses may find a role in nursing education to guide bedside procedures or facilitate asynchronous peer learning through recorded practice sessions. These targeted applications highlight how wearables can support individualized learning trajectories and more accurate assessments of clinical readiness.

From a policy perspective, addressing barriers to adoption is paramount. Cost-effectiveness analyses, technical standardization, and institutional investment in infrastructure are necessary to ensure equitable access. Furthermore, data governance protocols must be developed to safeguard learner privacy, especially given the sensitive nature of physiological and behavioral data collected through wearables. Faculty training also emerges as a priority—educators need

professional development opportunities to understand, interpret, and utilize wearable data meaningfully in both formative and summative assessment contexts.

This review also suggests that the integration of wearables may signal the emergence of a new theoretical paradigm in healthcare education—one that prioritizes data-informed, emotionally responsive, and simulation-enhanced learning. By moving away from static, one-size-fits-all instructional models, these tools support a dynamic and personalized educational ecosystem. Although some challenges persist—such as potential overreliance on technology, physical discomfort, or novelty effects—these can be mitigated through thoughtful implementation, inclusive design, and continuous evaluation.

Finally, this review reinforces the potential of wearables to drive a paradigm shift in clinical education—towards more individualized, data-driven, and performance-informed learning. While challenges such as cost, technical complexity, and novelty effects remain, the integration of these tools opens promising avenues for enhancing learner engagement, optimizing instructional strategies, and improving clinical competence. To solidify their role in health professions education, future research should investigate the longitudinal impact of wearable-enhanced learning, focusing on knowledge retention, skill transfer to real clinical settings, and ongoing professional development. Multisite trials, meta-analyses, and mixed-methods studies are especially needed to validate outcomes and guide the development of evidence-based standards for curricular integration.

In conclusion, wearables represent a set of heterogeneous yet complementary tools capable of enhancing various aspects of healthcare training. A nuanced understanding of each device's potential, coupled with theoretical rigor and institutional support, will be key to unlocking their transformative power. This review contributes a foundational step in this direction, laying the groundwork for more structured, impactful, and equitable uses of wearables in the education of future healthcare professionals.

### Limitations

According to the GRADE system (Goldet & Howick, 2013), 16 of the 20 studies included were classified as very low quality, 3 as low and only 1 as moderate. Although study quality was not a selection criterion, this rating highlights critical limitations in the current body of evidence. Most of the included studies are descriptive and observational in nature, which means they are not designed to test hypotheses or establish causal relationships. As a result, they cannot adequately assess the effectiveness of wearable-based interventions. This limitation also affects the external validity of the findings, as results from such studies may not be generalizable across different educational settings or learner populations.

Furthermore, the search strategy may have missed relevant studies (Lefebvre et al., 2019) due to heterogeneous terminology and challenges in identifying healthcare learners at different stages. To mitigate this, a unified DeCS/MeSH-based strategy was applied.

In addition, the exclusion of non-English studies and the narrow geographic scope of many included articles further constrain the generalizability of findings.

Finally, the absence of preregistration of the review protocol may limit methodological transparency and increase the risk of bias. Preregistration would have strengthened the credibility and reproducibility of the review by specifying key methodological decisions in advance.

### Conclusion

This review may suggest the transformative potential of wearables in healthcare education, indicating a possible shift from traditional pedagogical models toward more personalized, data-driven

approaches. Although explicit references to paradigm shifts remain scarce in the current literature, the accumulated evidence could point to a gradual redefinition of simulation-based learning and competency assessment. Wearables might facilitate real-time monitoring of physiological and behavioral data, while also enabling more nuanced and adaptive feedback that could potentially enhance the learner experience.

To fully harness this potential, further research is essential to develop robust theoretical frameworks and evidence-based strategies for integrating wearables into healthcare curricula. The GRADE evaluation underscored that most of the included studies relied on observational or descriptive methodologies. This methodological limitation hinders the ability to evaluate effectiveness reliably and reduces the generalizability of the findings to broader educational contexts. Therefore, future studies should prioritize randomized controlled trials to more rigorously evaluate the effectiveness of wearables and strengthen the external validity of the evidence base. Such research would support the systematic implementation of these technologies, ensuring they contribute meaningfully to educational outcomes and the advancement of clinical training practices.

In summary, this review identifies a typological diversity of wearable applications in healthcare education, reveals a gap in methodological rigor across the literature, and highlights the need for future research to validate effectiveness through high-quality trials. These findings can guide educators, researchers, and policymakers in making evidence-informed decisions regarding the integration of wearables into simulation-based learning environments.

### Declaration of competing interest

The authors declare that they have no known competing personal relationships or financial interests that may have influenced the study reported in this paper.

### CRediT authorship contribution statement

**Astrid Vidiella:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Silvia Reverté-Villarroya:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ramon Palau:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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### Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.teln.2025.10.003.

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