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Augmented reality in intensive care nursing education: A scoping review☆

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Objectives: This scoping review aimed to identify existing literature on the application of augmented reality (AR) in the intensive care unit (ICU) and analyse its current state of play regarding hands-on skills.
Background: Active learner engagement can greatly enrich educational outcomes. With the rise of immersive and interactive technologies, AR is progressively integrated into nursing education to enhance this aspect. Despite its potential, there is lacking evidence regarding the application of AR in ICU nursing education.
Design: A scoping review was conducted following the Arksey and O'Malley framework.
Methods: Six databases, including Medline, CINAHL, PsycINFO, EMBASE, ERIC and Web of Science, were searched from inception until the present without language restriction. Two reviewers independently performed selection and data extraction. The Pattern, Advances, Gaps, Evidence for Practice and Research Recommendations framework guided data analysis and results presentation. The protocol was registered with the Open Science Framework, Registration No. osf.io/36c25.
Results: Our search yielded 3135 articles, 24 of which were included in the review. Ten technological products were identified; Microsoft HoloLens and smartphones were used in eight and five studies, respectively. Seven studies evaluated the usability of AR applications using the system usability scale (SUS). Most of them demonstrated an excellent overall SUS score. Participants' satisfaction and confidence in using AR received favourable results. Finally, most studies found no statistically significant improvement in skill and knowledge performance.
Conclusion: The findings demonstrate AR's broad acceptance, utility and feasibility, highlighting its capacity to enrich educational experiences. However, a dearth of research has proved AR's effectiveness in ICU education.

1. Introduction

An intensive care unit (ICU) is a specialised and structured system designed to provide intensive medical and nursing care to people who are facing critical illness (Marshall et al., 2017). Critical illness is a state characterised by crucial organ dysfunction or life-threatening deterioration (Kayambankadzanja et al., 2022). Thus, patients' conditions in the ICU are complex and change rapidly and nurses need to apply their knowledge and skills to effectively evaluate symptoms, implement interventions and administer treatments, ultimately mitigating potential

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risks to patient well-being. Meeting the multifaceted care needs of critically ill patients necessitates ICU nurses possessing an arsenal of skills. This entails extensive clinical skills and proficient operation of medical equipment like ventilators, hemodialysis and cardiac or blood pressure monitors (Nobahar, 2016). They also need to respond to emergencies swiftly and address changes in patient's conditions promptly. To equip novice nurses with these competencies and skills, nursing education is of high importance. Studies have reported that better-educated nurses have been associated with improved survival rates for patients (Cho et al., 2015; Lasater et al., 2021). However, the sophistication and variety of critical nursing practice knowledge pose a significant challenge to nursing educators.

Until now, conventional teaching and simulation techniques have remained dominant in universities. Theoretical knowledge is primarily delivered by face-to-face lectures and psychomotor skill proficiencies are demonstrated and simulated using low-fidelity manikins (Koukourikos et al., 2021). Low-fidelity simulators (LFS) use non-computerized, static manikins that offer limited realism in replicating the characteristics of an actual patient. A recent study demonstrated that novices using LFS in cardiopulmonary resuscitation (CPR) training reported lower competence achievement compared with those trained with a high-fidelity manikin, a computerised simulation capable of mimicking indicators, like breath and heart sounds and pulses, dynamically responding to student interventions (Saad Shaaban et al., 2021). While offering a basic introduction to knowledge and skills, the blended traditional approaches lack active interaction and dynamic feedback. It is increasingly recognised as insufficient for preparing nursing students for the complexities of ICU care. Additionally, conventional teaching approaches require substantial teaching staff commitments and access to equipment and laboratory resources. This can limit opportunities for crucial hands-on skills practice, leading to student dissatisfaction and feelings of inadequate preparation. Studies revealed that novice nurses reported inadequate supervision, limited practice opportunities and a lack of preparedness for working in critical care settings (Ally et al., 2020; Masso et al., 2022; Serafin et al., 2022). However, competently performing various nursing procedures is paramount for ensuring safe, effective and patient-centered care. Given the shortcomings of traditional pedagogy, nursing educators are increasingly looking toward innovative, technology-based solutions to create more engaging, interactive and effective learning experiences for nursing students.

In recent years, augmented reality (AR) has rapidly emerged as a transformative tool in nursing education, offering a valuable supplement to traditional pedagogical methods, particularly given its immersive and interactive advancements (Aebersold and Dunbar, 2021). AR is a cutting-edge technology that blends digital content with the real world. Unlike virtual reality, which creates entirely immersive digital environments, AR overlays digital elements onto the real world. It enhances the actual world by incorporating digital elements such as images, text and animations through glasses or via tablets and smartphones (Makhataeva and Varol, 2020). Within the realm of nursing, simulation-based education is the primary means (Alexander et al., 2015). Reportedly, studies suggest that simulation-based learning can effectively substitute up to 50 % of clinical hours without compromising students' clinical reasoning, knowledge, or skills development while providing a risk-free and less stressful environment for students to practice skills and refine their abilities (Franklin and Blodgett, 2020; Mattila et al., 2020; Salameh et al., 2021). Given the complex technical requirements and specialised nature of ICU nursing education, AR-incorporated simulations have been suggested to enrich the hands-on experience by offering a realistic environment. Previous studies have shown that AR has been successful in training intubation and central line placement by superimposing anatomical structures, physiological data, or procedural guidance onto manikins in critical care education (Alismail et al., 2019; Lee et al., 2024). Additionally, He *et al.* (2022) conducted a randomised pilot study with AR-assisted mechanical ventilation training for nurses, showing lower assistance needs and a higher confidence level among those guided by AR-based instructions.

Furthermore, AR-based simulation has helped learners to make mistakes safely without risk to patients and learn from deliberate, repeatable practices to improve their performance. (Aebersold et al., 2018; Heo et al., 2022; Fealy et al., 2023; Lee et al., 2024). AR has also been reported to be beneficial in performing challenging procedures with psychological safety and enjoyment without exposure to increased stress (Aiello et al., 2023; Hiran et al., 2024). AR adoption in nursing education is emerging and so is structured teacher training in AR. However, supporting teacher training in other educational areas is developing worldwide, including providing hands-on experiences with AR tools and offering ongoing support and mentorship (Nikou et al., 2024), showing promise in enhancing student teachers' learning processes. Incorporating AR into ICU nurse training thus may potentially meet educational objectives, allow nursing students to practice skills in a safe and controlled environment and provide a more realistic and personalised learning experience, ultimately improving psychomotor skills transfer. Accordingly, this review aims to identify the existing literature on the application of AR technology in nursing education, particularly in the ICU and to explore the state of play in nursing education regarding hands-on experience and real-life situational training.

Before carrying out this review, a preliminary search in JBI Evidence Synthesis, Cochrane Database of Systematic Reviews, Cumulative Index to Nursing and Allied Health Literature (CINAHL) and Evidence for Policy and Practice Information (EPPI) was carried out to evaluate if any similar reviews on this topic area were completed or ongoing. To date, one scoping review has been undertaken to explore the application of AR in nursing education. This review was conducted in 2018 and searched for studies published until April 2018 which was older than five years (Wüller et al., 2019). The rapid advancements in AR technology, particularly within the last five years, necessitate an updated understanding of its use in nursing education, especially in ICU nursing education. Therefore, a synthesis of existing evidence is needed to identify what is currently known about the application of AR technology in intensive care nursing education. The key research questions are: 1) “What kind of AR technology is available for nursing education in the ICU?”, 2) “What types of hands-on skills and real-life clinical scenarios are currently being addressed through AR-based training programs in nursing education?”, 3) “What impact does AR have on learning outcomes and skill acquisitions?”.

2. Methods and designs

Scoping reviews are used to map the types of available evidence and explore the breadth or extent of the literature. They are valuable for exploring developing research areas and examining how research is performed on a specific topic (Peters et al., 2020). A scoping review was deemed appropriate as we aimed to identify all available AR technology used in nursing education, the variety of AR tools and their characteristics. This scoping review adhered to the established Arksey and O'Malley framework (Arksey and O'Malley, 2005), incorporating the updated Joanna Briggs Institute (JBI) guideline (Peters et al., 2020). Additionally, our team followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISM-ScR) checklists (Tricco et al., 2018). The PRISM-ScR statement comprises 22 elemental items that helped to guarantee the rigour and transparency of reporting the scoping review (Tricco et al., 2018). The protocol has been registered with the Open Science Framework, Registration No. osf.io/36c25.

2.1. Review aims and objectives

The present study is part of the EU-funded ERASMUS+ project, ALIAS (Augmented Reality in Intensive Care Education for Nursing Students: Enhancing Hands-on Experience and Preparing for Real-life

Situations), which aims to prepare final-year nursing students for real-life situations in the ICU and enhance the quality of care provided by nursing graduates by using AR simulations. The specific objectives of this review were: 1) to identify existing AR technology in nursing education and to identify its best practices and potential opportunities for implementation, 2) to evaluate the state of play in nursing education regarding hands-on experience and real-life situational training, 3) to assess the impact of AR adoption on learning outcomes and 4) to identify gaps and opportunities for improvement.

2.2. Search strategy

Six main electronic multidisciplinary databases were searched, encompassing Medline via ProQuest, CINAHL Plus, PsycINFO via EBSCOhost, EMBASE, ERIC and Web of Science. Additionally, our team conducted manual searches of grey literature sources, including Google Scholar, MIT xPRO and technical professional organisations such as IEEE Xplore and ACM Digital Library, along with relevant conferences (International Conference on Virtual and Augmented Reality Simulations and International Conference on Recent Advances in Augmented Reality) and journals (Frontiers in Virtual Reality/Augmented Reality and International Journal of Virtual Reality) in AR technology. Furthermore, the reference lists of included studies were screened for potential additional sources.

The search strategy was constructed following the Peer Review of Electronic Search Strategies (PRESS) guidelines (McGowan et al., 2016). Firstly, the translation of research questions employed the Population, Concept, Context (PCC) framework advised by JBI (Peters et al., 2020). Three key search concepts, including "ICU," "AR," and "nursing education," were identified. Secondly, the keywords of these three search concepts were exploded by applying the rules of synonyms, truncations, abbreviations and different spellings. Index terms, such as Medical Subject Headings (MeSH) and Emtree, were also identified according to their specific database rules. Finally, the Boolean operator combined "ICU" AND "augmented reality" AND "nursing education" using all identified keywords and index terms of each concept.

According to JBI recommendation, a preliminary pilot search was performed in two databases, including MEDLINE and CINAHL, with the assistance of a specialised librarian to test the search strategy's appropriateness (Peters et al., 2020). This followed a further analysis of keywords and index terms in the title and abstract of relevant papers to identify more. After the pilot search, one reviewer and a qualified librarian executed the complete search strategy across the six databases outlined previously, adhering to each database's specific search syntax and controlled vocabulary to draw the searches. The finalised search strategy underwent peer review by two additional reviewers to ensure comprehensiveness and rigour. Table 1 shows the search terms related to three main concepts. No language or publication date restrictions were applied, and the search was updated to include publications until December 2024.

2.3. Eligibility criteria and selection process

The inclusion and exclusion criteria were set up in line with the PCC and our review question (Peters et al., 2020). Studies that met the following criteria were included: 1) the population (P) focused on nursing students or registered nurses irrespective of their current department or specialisation; 2) the concept (C) was the use of AR technology as an educational tool; 3) the context (C) was any type of ICU setting or university. Studies involving nursing students from university settings having intensive care learning were eligible. Additionally, AR training programs implemented in ICUs were included, regardless of whether the participants were practising nurses or nursing students; and 4) the type of evidence sources were considered openly to include primary research studies (e.g., randomised controlled trials, mix-method studies, observational studies), systematic reviews, meta-analyses, grey literature (e.g., guidelines). Studies were excluded if they met the following criteria: a) conference abstract without outcomes reported; b) duplicate publications; c) no full text available; and d) non-English publications due to language limitations.

Table 1
Search terms related to three main concepts identified using the population, concept, and context approach.

Concepts	Keywords	Index terms
Intensive care unit	ICU OR CCU OR ITU OR HDU OR "emergency unit* '' OR "intensive care unit* '' OR "intensive therapy unit* '' OR "intensive treatment unit* '' OR "critical care unit* " OR "critical room* " OR "high dependency unit* "	**Medline (ProQuest):** Exact ("Intensive Care Units") **CINAHL Plus (EBSCOhost):** (MH "Intensive Care Units+") **EMBASE (Elsevier):** 'intensive care unit'/exp OR 'medical intensive care unit'/exp **PsycINFO (EBSCOhost):** DE "Intensive Care" **Web of Science:** no index terms (title and topic search only) **ERIC(EBSCOhost)**
Augmented Reality	"Augmented reality" OR "mixed reality" OR "Extended Reality " OR AR OR MR OR XR OR "simulated 3D environment" OR " computer modeling" OR "computer modelling" OR "computer simulation* " OR "simulated reality" OR "computerized simulation* " OR "computerised simulation* " OR "computer-mediated reality" OR VR OR "virtual reality"	**Medline (ProQuest):** Exact ("Augmented Reality" OR "Virtual Reality") **CINAHL Plus (EBSCOhost):** (MH "Augmented Reality") OR (MH "Virtual Reality+") **EMBASE (Elsevier):** 'augmented reality'/exp OR 'virtual reality'/exp **PsycINFO (EBSCOhost):** (DE "Augmented Reality") OR (DE "Virtual Reality+") **Web of Science:** no index terms (title and topic search only) **ERIC(EBSCOhost)**
Nursing Education	"Nursing education" OR "education N3 nursing" OR "nursing program* " OR "nursing programme* " OR "nursing training* " OR "nursing simulation* " OR "nursing curricul* " OR "nursing learning* " OR "nursing courses" OR " nursing apprenticeship" OR CPD OR CPE or "Continuing professional development" OR "continuous professional development" OR "Continuing Professional Education" OR "continuous professional Education" OR educat* OR simulat*	**Medline (ProQuest):** Exact ("Nursing Education Research" OR "Education, Nursing") OR Exact ("Simulation Training") **CINAHL Plus (EBSCOhost):** (MH "Education, Nursing+") OR (MH "Simulations+") **EMBASE (Elsevier):** 'nurse training'/exp **PsycINFO (EBSCOhost):** DE "Nursing Education" **Web of Science:** no index terms **ERIC(EBSCOhost):** DE "Nursing Education"

The selection process was performed systematically per the JBI methodology (Peters et al., 2020). First, all search results were handled with reference management software (EndNote ™) to remove duplicates. Subsequently, title and abstract screening, followed by full-text screening, were conducted in the systematic review management program Covidence (Veritas Health Innovation Ltd, Australia). Two reviewers independently screened all titles and abstracts and full texts against the pre-defined eligibility criteria. Covidence, employing Cohen's kappa, revealed moderate inter-rater agreement among reviewers, with kappa values of 0.32 and 0.41 for title/abstract screening and full-text review stages, respectively. Discrepancies between reviewers were resolved through a meeting discussion to reach a consensus. In cases where disagreements persisted, a third reviewer was consulted to make the final decision.

2.4. Data extraction

A template data extraction instrument by JBI was adapted and revised to assist the data extraction of this review (Peters et al., 2020). The charted results were first classified under two main categories, including study characteristics and characteristics of AR technology used in nursing education, highlighting their alignment with the review objectives. Our review team first performed a pilot data extraction by one reviewer and verified it by a second reviewer. After piloting five articles, information on the types of AR applications in nursing education (the varieties of hardware and software systems), kinds of hands-on skills trained or simulation scenarios, the evaluation of the AR technology, including usability, suitability, acceptability, feasibility and technological issues and its impact on learning outcomes, such as student engagement, confidence, satisfaction, knowledge retention and skill acquisition, were extracted. In addition, information about study characteristics encompassing authors, year, country, study design, research aims, sampling, participants and settings was retrieved. Data charting was carried out by one team member and cross-checked by a second reviewer. In instances of discrepancies, a third researcher was involved to verify the data charting.

2.5. *Data analysis and results presentation*

Data analysis and presentation of the results were guided by The PAGER (Pattern, Advances, Gaps, Evidence for Practice and Research Recommendations) framework (Bradbury-Jones et al., 2022). The result of the search, duplication removal and study selection process was presented using the PRISMA flow chart (Page et al., 2021). A descriptive summary of study characteristics of included studies was followed to report the overall patterning using the number, frequency and tabulation. Moreover, narrative synthesis explored the types of AR tools employed, the state of play of AR application in nursing education, specific hands-on skills addressed and the impact on learning outcomes using tabular presentation. The analysis further identified methodological and theoretical advancements, research gaps and considerations for implementing AR technology in nursing education.

3. Results

Following an extensive search across the chosen electronic databases and grey literature sources, 3135 records were initially retrieved. After eliminating duplicates, 2755 studies underwent titles and abstracts and full-text screening in line with the predefined eligibility criteria. On completion of the screening process, 24 studies emerged as meeting the inclusion criteria and were selected for analysis. The selection process and final inclusion of these studies are depicted in Fig. 1.

3.1. *Results of study characteristics*

Most studies (n = 10) took place in the United States of America (USA), followed by Spain (n = 3), Korea (n = 3), Japan (n = 2) and Turkey (n = 2). The remaining studies were conducted in Canada, China, Egypt and New Zealand (n = 1 each). Fig. 2 illustrates the distributional analysis of locations of included studies.

The year of publication ranged from 2015 to 2024, with more than 90 % of them published after 2020. The research methods employed across the studies varied. Of the included studies, approximately 38 % (n = 9) used a randomised controlled trial (RCT) design, three of which were pilot RCTs, comparing the effectiveness of AR applications to traditional teaching methods. 25 % of the studies (n = 6) employed a mixed-methods approach, with three being pilot studies. An additional four studies were designated as pilot feasibility studies. Furthermore, three studies employed a cross-sectional survey design and two used a quasi-experimental pre-post design. The sampling sizes of the included

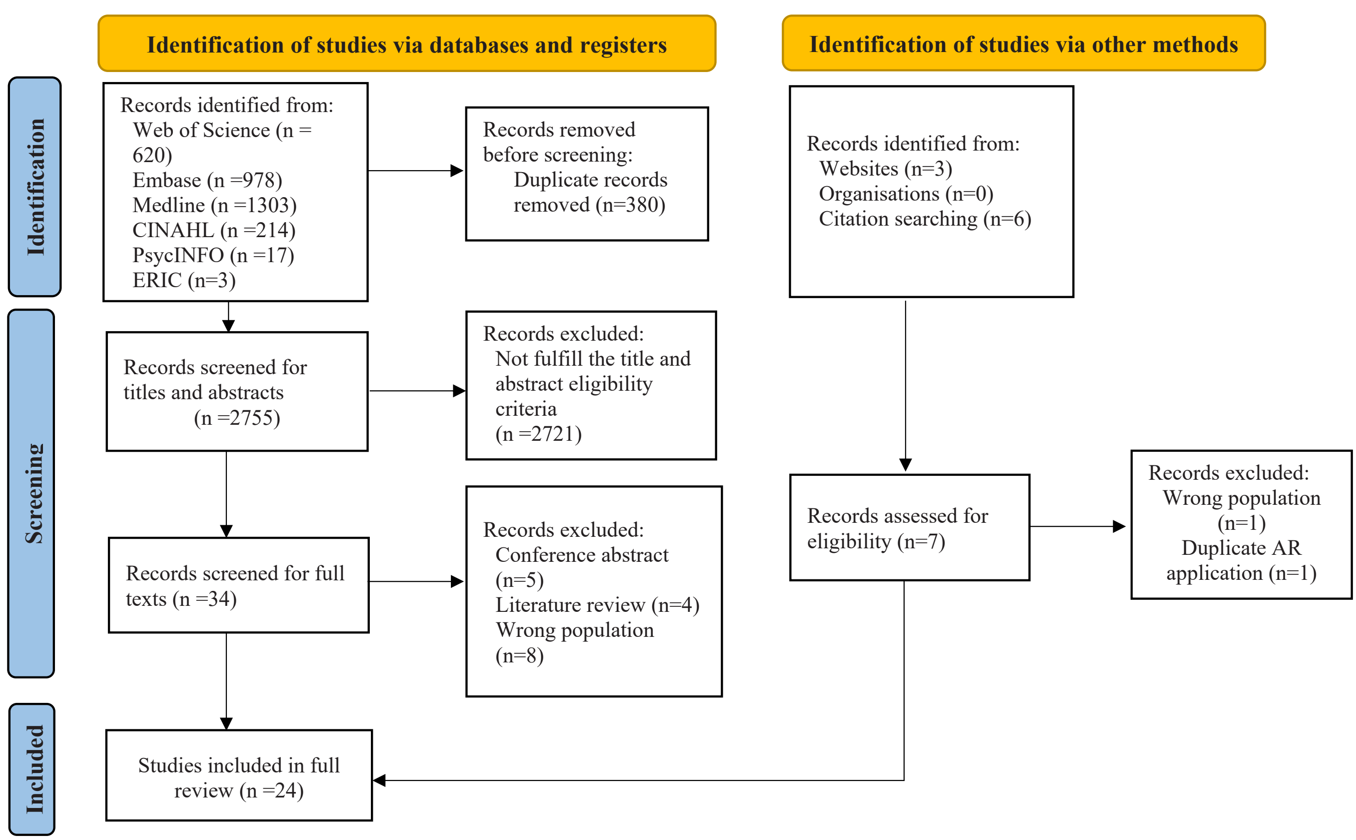

Fig. 1. PRISMA flow chart for the study selection.
From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

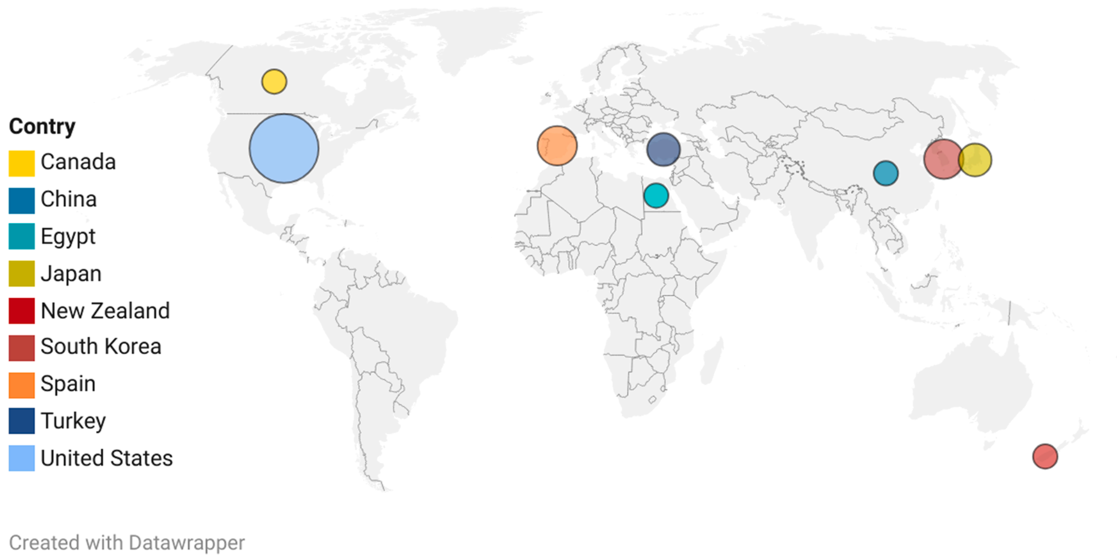

Fig. 2. Distributional analysis of the geographical location of included studies.

studies ranged from 12 to 410 participants. Overall, the included studies comprised a study population of 1767 participants. Most studies (80 %) implemented AR-based learning intervention in university settings for nursing students, primarily focusing on undergraduate students (first year to final year), while a small number of studies involved Master's degree programs or Doctor of Nursing Practice programs. In contrast,

Table 2
Characteristics of augmented reality hardware and software.

Author/ Year	Hardware	Software/Program	Application	Controller/ Accessory
Yoo *et al.,*2023	Microsoft HoloLens 2	Microsoft Dynamic 365 Guides		
Heo et al.,(2022)	Microsoft HoloLens 2	Microsoft Dynamic 365 Guides		Microsoft Dynamic 365 Remote Assist
Lee et al.,(2024)	Microsoft HoloLens 2	Microsoft Dynamics 365 Guides		
Escalada-Hernandez et al., (2024)	Microsoft HoloLens		ARSim2care	
Leary et al., (2020)	Microsoft HoloLens	CPReality system		
Liang *et al.,* 2020	Microsoft HoloLens	FaceGen and The KEG algorithm (Kanade-LucasTomasi Enhanced by Global constraints)		The fiducial marker AprilTag for the HoloLens tracking location
Rummel et al., (2023)	Microsoft HoloLens 2 or Smartphone devices		GigXR's HoloPatient	
Nakazawa et al., (2023)	Microsoft HoloLens 2 or Tobii Pro Glasses 3	AR-based care training system HEARTS (Humanitude AR Training System)		
García-Pazo et al., (2023)	BNEXT head-mounted display+			High-fidelity manikin
Arakida *et al.,* 2023	VIVE Pro by HTC Co., Ltd., in Taiwan.	Video see-through HMD system, the spatial position-tracking system		3D-printed translucent tracheal model Suction catheters point with a magnet inserted
Anderson et al., (2021)	not specified			
Anderson *et al.,* 2022	AresAR	Prepackaged acute care scenarios.	HoloLens Tips	
Menon et al., (2022)	Magic Leap One	QR marker was placed on the manikin for hologram placement.		Vuforia SDK used for marker detection
Vaughn et al., 2016	Google Glass (Google, Mountain View, CA)			
Kim et al.,(2021)	Vuzix smart glasses		Application programming interface 22	
Chao et al., (2021),	HTC Vive			HTC VIVEPAPER technology
Rodríguez-Abad et al., (2022)	Smartphone or tablet	HP Reveal® and Aumentaty Creator®		
Aebersold et al., (2018)	iPad	Anatomy-augmented virtual application, combining video with 3D computer graphics		The iPad recognises taps, moves, and gestures
Garrett et al., (2015)	Smartphones or iPads		Layar application	
Avci and Kilic, (2024)	Tablets		Magnet platform	
Kurt & Oztürk, 2021	Android-based smartphone	UNITY3D, Vuforio, 3D Max, After Affect, and Camtasia software		
Herbert et al., (2021)	Smartphones		Apple's ARKit 2	
Younes Othman et al., (2024)	Smartphones		Assemblr Studio and Kahoot games	
Bliss et al., (2022)	Projector-AR	Standard Agile software		The Smart Wand

only five studies applied AR technology in critical care settings to train practising nurses.

3.2. Results of the application of different technological AR tools

The AR application consists of software and hardware elements. The hardware consists of the physical devices that execute the functions. In contrast, the software provides the instructions that dictate how the hardware operates and interacts to create the augmented reality experience in the real world (Arena et al., 2022). Various types of hardware devices are used in AR applications, including smartphones and tablets, computers, smartwatches, head-mounted displays (HMDs) and spatial projectors (Oun et al., 2024). Among the 24 studies analysed, HMD was the most prevalent hardware (n = 15). Specifically, the Microsoft HoloLens was used in eight studies for projection (see Table 2). In addition to Microsoft HoloLens, other HMDs employed, each in single research, included the BNEXT head-mounted display+ , HTC VIVE Pro, AresAR, Magic Leap One, Google Glass, Vuzix smart glasses and HTC Vive. Concerning the software components, the Microsoft Dynamic 365 Guide program was the most prevalent choice (n = 3). Other options differed across the reviewed studies (see Table 2). Specially anderson et al. (2021) did not disclose the details of the headset.

Eight studies diverged from using HMDs, opting for mobile AR applications deployed on smartphones or tablets. These studies showcased a diverse range of software systems or applications, including HP Reveal®, Aumentaty Creator®, Layar, Magnet, UNITY3D, Vuforia, 3D Max, After Effects, Camtasia, Apple's ARKit 2 and a custom anatomy-augmented virtual application. In contrast to both HMDs and mobile devices, a single study used spatial projectors to create a Projected Augmented Reality experience. This unique setup employed custom-developed Standard Agile software in conjunction with a handheld controller called "The Smart Wand" (see Table 2).

3.3. Results on hands-on skills and real-life situational training

A total of 18 different nursing skills and knowledge were identified in the reviewed studies (see Table 3). The included hands-on skills were categorised into three groups: basic nursing procedures, advanced skills and simulations and assessments. Basic procedures included endotracheal aspiration, nasogastric tube skills, intravenous catheter placement, subcutaneous, intramuscular, intravenous injections, blood transfusion and intradermal injection administration and wound care. Advanced skills encompassed mechanical ventilation setting and alarm handling, extracorporeal membrane oxygenation (ECMO) setup and lumbar puncture. Finally, simulations and assessments included CPR training, stroke assessment, communication skills, triage skills, cardiopulmonary assessment skills and clinical scenario simulations, including acute asthma exacerbation, myocardial infarction, heart failure, asthma and anaphylaxis scenarios. Basic nursing procedures and advanced skills were commonly simulated using AR technology by superimposing holographic images or video onto a mannequin or using anatomy-augmented virtual simulation that integrates video with three-dimensional computer graphics, enabling students to visualise the intricate anatomical structures to step-by-step guide students through the procedural training. In contrast, the simulations and assessments training usually educated students by establishing real-life scenarios like heart failure, stroke and asthma. Students were placed in a simulated environment using the visualisation of holographic standardised patients to identify the symptoms and take action to respond to the changes. Mechanical ventilation and nasogastric tube training were the most frequently trained skills (n = 3), respectively. Followed by wound care, intravenous injection, stoke assessment and endotracheal suctioning (n = 2 each). Other skills or knowledge were all assessed once.

3.4. Results of the evaluation of the use of AR

The measured outcomes mainly focus on the realism, usability, acceptance, suitability, feasibility and satisfaction of the application of AR tools or self-confidence, simulation experience, skill acquisition, engagement, self-efficacy and knowledge test of the participants (see Table 3). The usability of AR applications was evaluated in seven studies using the system usability scale (SUS). Most of the studies demonstrated an excellent overall SUS score, above the average, indicating the ease of using AR among students. Acceptance of AR was tested in two studies using the Technology Acceptance Mode scale (TAM) and results showed that many participants rated "agree" or "strongly agree," showing acceptable use of the AR training. Eleven studies assessed participant's satisfaction with using AR learning. Satisfaction reported by the included students who used the AR for training was marginally higher. Analysis across various studies consistently revealed significant learning satisfaction in AR groups. In addition, one study conducted by Anderson et al. (2021) using a mixed method identified a central theme: realism, seeing the patients and associated injuries, which exemplifies actual patients. Likewise, in the study of García-Pazo et al. (2023), they observed that 67.6 % of the students felt physically present in an ICU environment. However, specific barriers were identified, for instance, technical issues such as slow response times and incompatible smartphones (Garrett et al., 2015), small screen sizes, touch sensors, fogged lenses with masks, heaviness and heat after a period, eye fatigue and AR sickness (Kim et al., 2021).

In addition to the evaluation of the feasibility of AR application, 12 studies appraised the skill or knowledge performance of the participants. Interestingly, only two studies proved that AR was superior to conventional teaching. Kurt and Öztürk (2021) conducted an RCT to evaluate the effect of Mobile Augmented Reality (MAR) on nursing students' knowledge and skills related to subcutaneous, intramuscular and intravenous injections. Their findings demonstrated that the experimental group, using MAR, achieved significantly higher post-test and persistence test scores for knowledge than the control group ($p < 0.001$). Furthermore, the experimental group exhibited significantly higher skill levels in injection practices ($p < 0.001$). Similarly, Aebersold et al. (2018) showed that correctly placing the nasogastric tube through all the checklist items was significantly better in the AR group than the control group. In contrast, Leary et al. (2020) and Rummel et al. (2023) found that traditional methods yielded better outcomes. The other studies found no significant differences between AR intervention and traditional training. Nonetheless, Heo et al. (2022) observed significantly less procedural assistance needed by the AR group than the manual training group. Specifically, the median number of steps requiring assistance was two for the manual group and zero for the AR group ($p = .03$). Furthermore, a more significant proportion of participants in the manual group (93.3 % vs 47.7 %; $p = .02$) requested assistance, with a total of 33 requests compared with only 13 in the AR group. Furthermore, although no difference between groups, Chao et al. (2021) and Othman et al. (2024) demonstrated that knowledge scores improved significantly after the intervention of AR. Particularly, Othman et al. (2024) reported that knowledge test mean scores significantly improved between the pre-test ($p < 0.001$ [$\eta2 = 0.515$]), immediate post-test ($p < 0.001$ [$\eta2 = 0.146$]) and retention test ($p < 0.001$ [$\eta2 = 0.515$]) in the AR group.

Several studies investigated the impact of AR on learner confidence, self-efficacy, engagement and motivation. Four studies reported that participants using AR reported higher levels of confidence and motivation compared with the control group (Vaughn et al., 2016; Heo et al., 2022; Lee and Han, 2022; Avci and Kilic, 2024). However, one study observed no significant difference in confidence levels between AR and control groups (Chao et al., 2021). Regarding self-efficacy, Othman et al. (2024) used the Learning Self-Efficacy Scale and found significantly higher scores in the AR group ($p < 0.001$ [0.662]). Positive engagement results were also reported in two studies focusing on AR intervention

Table 3
Summary and analysis of included studies.

Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
Yoo *et al.*, 2023 Korea	Mixed methods: semi-structured interviews and surveys	To educate ICU nurses on the proper use of mechanical ventilation and ECMO with the use of AR technology. To implement the AR learning platform and evaluate the outcomes.	ICUs	N_{total}= 24/ n = 12 in the ventilator training group. n = 12 in the ECMO training group. ICU staff nurse, work experience (range)= 1–13 yrs.	Mechanical ventilator training includes system and alarm setting. ECMO training includes setting up ECMO devices, handling disruptions, and addressing alarms.	*Usability:* System Usability Scale (SUS) *Acceptance:* Technology Acceptance Mode scale *Satisfaction*: self-developed questions	*Appropriateness of educational content:* interview	The evaluation of AR-based education was positive with participants and improved their clinical performance. Participants perceived that self-direct learning improved.
Heo et al., (2022) Korea	Pilot RCT	To determine the effectiveness and feasibility of self-directed AR-based learning for nurses to set up ventilators and evaluate the precision and assistance required for independently completing the procedure.	ICUs	N = 30/ AR group (n = 15). Printed manual group (n = 15). Nurses without experience with ventilator setup or AR systems from nursing departments other than ICUs.	Mechanical ventilation: The training lasted more than 20 min and detailed the entire process (from preparing materials to setting up the initial ventilator mode before connecting to the patient), with 35 steps.	*Usability*: System Usability Scale (SUS) *Confidence and suitability of AR*: self-developed questions	*Skills:* 1 point for each step if finished within 5 min. *Required assistance:* the number of steps and the number of participants who required assistance, assistance frequency, and time	*Skills performance:* Overall performance scores and duration were no different between groups. *Assistance*: The manual group required more help than the AR group. The median number of steps needed assistance per participant was greater in the manual group compared to the AR group (median 2 vs. median 0; p = .03). The manual group had a greater proportion of participants who requested assistance (14/ 15, 93.3 % vs. 7/ 15, 47.7 %; p = .02). The manual group with 33 requests for assistance was recorded, whereas 13 requests were in the AR group. *Confidence and Suitability:* AR has higher confidence and suitability ratings than the manual group. *Usability*: only surveyed AR group, the median SUS score was 55 (IQR 47.5–67.5).
Othman et al., (2024) Egypt	RCT	To examine the effect of the combined use of gamification and AR in teaching	Faculty of Nursing, Damanhour University	N = 410/ AR group (n = 205) Traditional lecture group (n = 205)	Mechanical ventilation	*Satisfaction:* Student satisfaction questionnaire	*Knowledge:* self-developed questionnaire *Learning motivation:* Instructional	*Knowledge:* knowledge test mean scores significantly improved between the pre-

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
		mechanical ventilation.		Third-year undergraduate nursing students enrolled in the Critical Care Nursing (I) course			materials motivation survey (IMMS) *Self-efficacy:* Learning self-efficacy scale	test (*p* < 0.001, [η2 =0.515]), immediate post-test (*p* < 0.001 [η2 =0.146]), and retention test (*p* < 0.001 [η2 =0.515]) in the AR group. *Self-efficacy score* was significantly higher in the intervention group *(p < 0.001* [Cohen's d =0.662]). *Motivation scores* were significantly higher (p < 0.001, [ηp2 = 0.558]) than that for the traditional strategy. 98 % of students in the intervention group were satisfied.
Lee et al., (2024) USA	Cross-sectional study design	To investigate the usability, feasibility, acceptability, and engagement of AR learning for lumbar puncture.	A course on acute care advanced nursing procedures	N = 24/ 18 were adult acute care gerontology students, and 6 were paediatric acute care students	Lumbar puncture skills	*Usability:* System Usability Scale *Acceptability:* The Acceptability of Intervention Scale	*Engagement:* Engagement Scale *Faculty time*	*The overall SUS score* was 71.25, above average, indicating AR is not difficult to use. *Acceptability*: More than 88 % of participants rated "agree" or "strongly agree," showing acceptable procedure training. *Engagement*: Ten questions had an average score of 8.0 or higher. Students felt AR was better than traditional content, increasing their confidence and motivation. *Faculty time* was reduced by 75 % compared to traditional training. *Qualitative assessment* reflected five main themes: ease of use, interactive, self-paced, independent, and step-by-step.

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
Escalada-Hernandez et al., (2024) Spain	Cross-sectional study design	To assess the usability and user expectations of an augmented reality application for smart glasses (Microsoft HoloLens) used for training invasive procedures	three universities located in the northeast of Spain	N = 61/ Students of bachelor's degrees in nursing	Intramuscular injection, nasogastric tube insertion, endotracheal intubation, and suctioning via tracheostomy tube	*Usability:* System Usability Scale (SUS)	*User expectation:* self-developed questions	The mean score of the SUS was 73.15, and 62.4 % (n = 38) of the participants considered their experience with the application to be excellent or good. Regarding user expectations, more than 90 % of students indicated that using AR improves their motivation and stimulation in learning, their content retention, and their anatomical understanding.
Leary et al., (2020) USA	Pilot RCT	To evaluate the effectiveness of AR in CPR training.	Simulation centre, or School of Nursing	N = 100 AR group (n = 50) Standard CPR training group (n = 50) Nurses, doctors, and advanced nurse Practitioners	CPR training		*CPR skills:* chest compression (CC) rate of 100–120 compressions per minute (CPM) and chest compression depths of 50 and 60 millimetres (mm)	The mean CC rate CPReality group was 121 ± 3 compared with the standard training, which was 114 ± 1 cpm ($p < 0.006$), CC depth was 48 ± 1 mm vs. 52 ± 1($p = 0.007$), respectively. Traditional training group showed better skill performance. In the post-survey, 79 % of CPReality subjects agreed AR provided a realistic patient presence compared with 59 % ($p = 0.07$) of subjects in the standard CPR manikin cohort.
Liang *et al.,* 2020 USA	Pilot feasibility study	To evaluate the feasibility and usability of mixed reality in nursing education.	University of Michigan School of Nursing	N = 85/ Final-year nursing students	Stroke assessment: FAST assessment includes evaluating facial symmetry, arm strength, speech, and time to call for help	*Feasibility and usability*: 33 survey questions		Nursing students (91.8 %) successfully identified the stroke symptom and completed the FAST procedure wearing the HoloLens. Most students enjoyed the simulation and felt extended reality would be a useful educational tool

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
								for clinical training and healthcare. Barriers: The headset is heavy and uncomfortable. A small number of students feel dizzy, in pain, and itchy.
Rummel et al., (2023) New Zealand	Mixed methods: quasi-experimental pre-post design and focus group interview	To explore how the HoloLens could help bridge theoretical knowledge to practice in simulated patient scenarios in inpatient and community contexts.	University	N = 20 AR group (n = 20) Face-to-face traditional teaching (the rest of the students) Final-year nursing students	Myocardial infarction, stroke, asthma, and anaphylaxis scenario		*Knowledge test:* Multiple choices questions	HoloLens substantially improved the student learning experience; however, face-to-face interactions yielded better outcomes. Participants highly valued the HoloPatient's 3D holographic health scenarios. Challenges include time constraints, problems with headset adjustment, and insufficient user training.
Nakazawa et al., (2023) Japan	RCT	To evaluate the effectiveness of AR for communication training.	Clinical Nursing Department at Bukkyo University	N = 38/ AR group (n = 16) Control group (n = 16) First-year to final-year nursing students.	Communication skills and empathy		Japanese Big-Five Scale and the Jefferson Scale of Empathy (JSE) Health Profession Students' version. *Physical behaviour feature:* first-person videos retrieving face-to-face distance and pose, eye contact, and the length of speech	The empathy score for the control group had no significant change, whereas that of the AR group significantly increased (Pre: 110.43 (17.99), Post: 117.65 (10.58), p = 0.03)). The face detection rate, occurrence rates when the face-to-face distance was less than 700 [mm], occurrence rate of eye contact, and length of speech significantly increased in the AR group. However, no significance was found in the Doll group. Face-to-face distance was not different in the AR and doll groups. Face-to-face posture

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
								(angles) significantly decreased in the AR group, while no significance was found in the Doll group.
García-Pazo et al., (2023) Spain	Cross-sectional study	To evaluate the utility of VR in the nursing assessment of critically ill patients, the degree of physical realism of the scenario, and the acceptance and satisfaction with VR.	University of the Balearic Islands	N = 175 third-year undergraduate nursing students enrolled in the critical care nursing module	Assess the hemodynamic, respiratory, and neurological status of the patient	*Sense of presence* *Usability:* System Usability Scale (SUS) *Utility*	*Satisfaction:* questionnaire	The SUS questionnaires indicated that 67.6 % of the students felt physically present in an ICU environment. Students were satisfied with using VR, with scores above four in all dimensions. The software was easy and pleasant to use.
Arakida *et al.,* 2023 Japan	RCT	To compare the learning outcomes of the three—mode (learning, practice, and test) AR tool with traditional training To identify potential uses of the AR tool.	Three universities	N = 54/ AR (n = 29), control group (n = 24). University students receiving basic nursing education and university faculty (n = 9)	Endotracheal aspiration skill		*Skills:* 32 checkpoints *Perception from students and faculty on the use of AR tools.*	There was no significant difference in skill scores between the two groups and no significant difference in the required time. Interviews with the faculty indicated that AR is helpful. Qualitative feedback from students favoured AR, with four expressing eye fatigue and VR sickness.
Anderson et al., (2021) USA	Pilot mixed methods: survey and open-ended questions	To evaluate the usability and effectiveness of the AR triage scenario.	Adult-Gerontology Acute Care Nurse Practitioner student curricula	N = 12 Nurse Practitioner students (N = 8) and other volunteers, including faculty, instructors, adjuncts, and simulation personnel (n = 3)	Triage skills	*Usability*: System Usability Scale (SUS) *Effectiveness:* Simulation Effectiveness Tool-Modified	*skill*: Open-ended questions	The mean SUS score was 57. Open-ended question comments included enjoying the learning experience and appreciating the debriefing, its use for visual learners, and the reality of the experience. Realism was an emerging theme, and seeing the patients and associated injuries helped with learning. Barriers: technical glitches and side effects

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
								experienced with the device.
Anderson *et al.*, 2022 USA	Pilot mixed methods	To explore integrating AR learning into the pre-brief phase with acute care scenarios.	Adult-gerontology acute care nurse practitioner education	N = 12/ Nurse practitioner students	Prebrief for Acute Care Simulation (immersive scenario on myocardial infarction)	*Usability*: System Usability Scale (SUS) *Effectiveness*: Simulation Effectiveness Tool-Modified	*Amount of time Participant side effects*: Virtual Reality Sickness Questionnaire.	Usability was less than average, mean was 58.96. The side effects were oculomotor. The mean simulation time was 15.41 min. The SET-M for the pre-brief portion had a mean of 3.00, indicating its effectiveness.
Menon et al., (2022) USA	Pilot RCT	To evaluate the effectiveness of AR-based learning of physical assessment skills of heart, lung, and thorax assessment compared with non-AR learning.	University	N = 17/ sophomore-level undergraduate nursing students AR group (n = 10) Control group (n = 7).	Cardio-Pulmonary assessment skills: Five variations of lung sounds were made available for different training scenarios, including bronchial, vesicular, bronch-vesicular, and wheezing sounds. Heart sounds included S1 and S2.		*Student Satisfaction and Self-Confidence:* The NLN Student Satisfaction and Self-Confidence in Learning *Skills performance:* The assessment rubric developed by the researcher.	Observation 1: The AR group achieved higher scores in examining differences in individual components of the assessment rubric. Satisfaction reported by the students following the NLN guidelines was marginally higher for students who used the AR for training, at 4.6, whereas students in the control group reported 4.4. Observation 2 (at the end of the semester): no difference.
Vaughn et al., 2016 USA	Pilot feasibility study	To describe an innovative hybrid simulation using an AR headset to increase realism in a high-fidelity simulation	A nursing school located in the southeastern USA	N = 12/ students in their second or third semester of an accelerated Bachelor of Science in nursing program.	Acute asthma exacerbation scenario	Simulation Design Scale (SDS)	Self-Confidence in Learning scale (SCLS)	The students scored the simulation design favourably, with mean scores on the SDS ranging from 4.81 to 4.83. The SCLS results indicated that AR was a favourable addition to the simulation-learning environment (4.65 ± 0.65). AR increased motivation and made them feel more confident.
Kim et al., (2021), Korea	Pilot feasibility study	To develop a smart glass-based nursing skills training program and to	University	N = 30/ undergraduate nursing students	Blood transfusion and intradermal injection administration	*Usability Test:* 16-item questionnaire and open-	*Learning Satisfaction:* 7-item questionnaire	*Nursing Competency*: Statistically significant improvement

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
		evaluate its feasibility and usability.				ended questions.	Nursing *Competency*	was achieved in both skills after the intervention. Many students found smart glass-based skill training interesting, convenient, and helpful. Barriers: small AR sickness sizes, touch sensors, fogged lenses with masks, heaviness, and heat after a period.
Chao et al., (2021) Taiwan, China	RCT	To examine the effects of an immersive 3D interactive video program in improving nursing students' NG tube feeding skill competence.	one university in northern Taiwan	N = 45 AR group (n = 22) comparison group (n = 23) nursing students who had never acquired the skills of NG tube feeding	Nasogastric tube feeding skill		*Knowledge:* nasogastric tube feeding quiz (NGFQ) Confidence: a confidence scale (C-scale) *satisfaction:* a satisfaction questionnaire	Knowledge scores and confidence improved significantly in both groups after the intervention and one month after the intervention. Nursing students were more satisfied with learning NG tube feedings using AR (M = 43.27, SD = 5.12) than those in the comparison group (M = 39.48, SD = 5.89).
Rodríguez-Abad *et al.,* 2023 Spain	Two quasi-experimental studies	To describe AR-based learning experience on academic performance and learning determinants. To compare AR-based online learning with face-to-face learning.	the School of Nursing at the University of Santiago de Compostela	N = 111/ Sophomore undergraduate nursing students AR group (n = 72) Control group (n = 65)	Wound care skill: leg ulcers, including introductory contents on leg ulcers, ankle-brachial index test, dressings, and lower limb compression therapy.	*Learning experience:* Ferrer-Torregrosa et al. questionnaire	*Knowledge and skills test:* self-developed questions *Attention, Relevance, Confidence, and Satisfaction*: Instructional Material Motivational Survey	The knowledge obtained by the students after online AR learning was superior to the pre-test scores. AR online group scored higher in *Autonomous Learning and 3D Comprehension than its* face-to-face counterparts. On the *Attention* dimension of the IMMS the face-to-face group scored higher than their online counterparts.
Aebersold et al., (2018) USA	Mixed methods: RCT and survey	To evaluate the impact of anatomy-AR-based procedure training on nasogastric tube placement skills	A large Midwestern institution	N = 69/ AR group (n = 35) The control group (n = 34) watched video and didactic content. Sophomore and	Nasogastric tube (NGT) placement skills 20–25 min	*Feasibility and satisfaction:* survey and open-ended questions	*Skill Competency*: a 17-item NGT skill checklist	Competency was better among participants in the AR group. 86 % of participants rated AR as superior to other procedural

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
				junior nursing students were attending a baccalaureate nursing program.				training programs. Participants perceived AR modality as realistic, easy to use, and enjoyable. AR group perceived AR as more helpful in identifying landmarks, visualising internal structures, and being interactive and novel. Open-ended questions indicated AR has interactivity, yet it has barriers to access and pace.
Garrett et al., (2015) Canada	Exploratory action-research-based pilot mixed study: surveys and focus group	To explore an initial proof-of-concept design using AR to supplement clinical lab skills.	A medical-surgical course at the university	N_{total}= 160/ undergraduate first-year nursing students (n = 120) and final-year students (n = 40)	Clinical skills laboratory: Pleural drainage, syringes and needles, sharps containers, oxygen delivery, handwashing and infection control, catheter bags, and tracheostomy equipment	*Student perspectives on AR implementation and value*: questionnaire *Accessibility*: interview	*Satisfaction:* online survey and interviewed	Students expressed comfort with the technology, and students and faculty identified the ability to access resources to support self-directed learning and review of skills as positive attributes of using AR. Students gave positive feedback on mobile access and having AR resources available "at the bedside". Barriers: slow response times and incompatibility.
Avci and Kilic, (2024) Turkey	RCT	To determine the efficacy of AR applications on intravenous catheter placement skills and evaluate satisfaction in learning and self-confidence levels of nursing students.	Nursing department of a university	N = 91/ AR (n = 47), control group (n = 44). Second-year nursing students finished the Fundamentals of Nursing course without catheter placement skill training.	Intravenous (IV) Catheter Placement skill		*Skills:* The IV catheter placement procedure steps were developed by the researchers. *Duration of the procedure. Satisfaction and Self-confidence:* Student Satisfaction and Self-Confidence in Learning Scale.	There was no significant difference between the groups regarding the average scores for IV catheter placement skills, the time taken to perform the procedure, or variance in the satisfaction score. The mean score for self-confidence was significantly higher in the AR group (31.38

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
								± 3.26) than in the control group (29.06 ± 3.60) ($p < .05$).
Kurt & Oztürk, 2021 Turkey	RCT	To evaluate the effect of Mobile Augmented Reality (MAR) educational materials on the knowledge and skill levels of nursing students on injection practices.	Nursing department of the health sciences faculty of a university	N = 122/ first-year students Mobile AR group (n = 64). Control group (n = 58)	Injection practices (subcutaneous, intramuscular, and intravenous)		*Knowledge test:* self-developed questions *Skill levels:* Injection practices evaluation checklists	90.6 % of the students stated the laboratory process was efficient, 78.1 % described having a solid picture of how to perform injections, and 70.3 % could efficiently perform the injection practices. 68.8 % stated increased motivation, 64.1 % stated improved self-confidence and 54.7 % stated decreased fear of the injection procedure. No statistically significant difference was found between the groups regarding pre-knowledge test scores ($p > 0.05$). The AR group's post-knowledge and persistence knowledge test scores were higher than the control group ($p < 0.001$). Skill levels were found statistically significant in the AR group regarding SC, IM, and IV injection practices higher than in the control group ($p < 0.001$).
Herbert et al., (2021) USA	quasi-experimental, pretest-post-test design	To develop an AR app on heart failure for remote training of nursing students To compare it against recorded video lectures.	Bachelor of Science in Nursing program at the university	N = 33/ AR group (n = 19) Control group (n = 14) junior nursing students	Heart failure	*Satisfaction and usability:* self-developed survey questions	*Knowledge gained:* Heart Failure Assessment (HFA)	Pretest and post-tests for the groups showed that using the app did not improve student scores. No significant results between the two groups for completion time ($p = .114$) and overall test accuracy ($p = .075$).

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Author/ Year/ Country	Designs	Aims	Settings	Target population & sample size (N)	Hands-on skills trained	Outcomes measured		Results/Findings
						AR technology	Participants' performance	
								Participant feedback indicated for the AR app, adjustability of HR and SV, ease of changing settings, and visual arrows were most helpful.
Bliss et al., (2022) USA	Pilot feasibility study	To describe a Projected Augmented Reality P-AR prototype for its potential to enhance nursing education about pressure injuries.	School of nursing in a large Midwestern public university	N = 32/ nursing students (n = 27) and faculty (n = 5). Students in pre-licensure baccalaureate and Master's degree programs and Doctor of Nursing Practice programs.	Wound care: pressure injuries ranging from risk factor identification to treatment.	*User-friendliness engagement effectiveness usefulness realism system:* survey and open-ended question		Median scores were 5 (strongly agree) and 4 (agree) for user-friendliness, engagement, effectiveness, usefulness, and overall impression of the system. Satisfaction was 5 (very satisfied) and 4 (satisfied) for "innovation," "engagement," "user-friendliness," "effectiveness," "usefulness," "appearance," and "quality," except "realism" received a neutral rating, and open-ended questions identified the barrier of not being realistic.

(Bliss et al., 2022; Lee and Han, 2022). Specifically, Rodríguez-Abad et al. (2022) demonstrated that the online AR group achieved higher scores in autonomous learning and 3D comprehension compared with their control counterparts.

4. Discussion

This scoping review examined the existing applications and potential of AR technology in nursing education, with a focus on the identification of hands-on skills and real-life simulations and evaluation of the learning outcomes. Our findings revealed a notable increase in AR adoption in nursing education since 2020. This burgeoning trend is likely attributed to the Coronavirus-2019 pandemic, which heightened the need for remote learning (Herbert et al., 2021; Nakazawa et al., 2023) and recent advanced developments in AR, especially the release of the product Microsoft HoloLens 2 in November 2019 (Vidal-Balea et al., 2020), which significantly accelerated the implementation of AR technology in education. Despite this recent growth, the integration of AR as a pedagogical tool in nursing education remains limited, especially in ICU nursing training. This gap is partly due to the scarcity of evidence on AR's effectiveness in nursing education. Most included studies recruited a small sample size in a singular site, making it hard to generalise the data to a larger context. Additionally, the predominance of pilot studies further highlights the nascent stage of AR research in nursing education. Geographically, investigations were concentrated in the USA, with limited research emanating from Europe and its use in nursing education remains underexplored in Europe. Despite the boom in AR adoption, more research is warranted in future investigations, particularly the conduct of randomised controlled studies to test the effectiveness and efficacy of AR in nursing education.

The included studies have extensively evaluated the usability of AR technology, consistently revealing its wide usability, utility and feasibility among participants. Positive attitudes towards AR-based education were prevalent, reflecting an acknowledgement of its potential to advance learning in various skill simulations and knowledge acquisition (Kim et al., 2021; García-Pazo et al., 2023; Escalada-Hernandez et al., 2024; Lee et al., 2024). This positive assessment of AR's usability aligns with previous reviews in intensive care medicine (Kanschik et al., 2023) and paediatric intensive care education (Goldsworthy et al., 2023). In addition, the review of AR technology underlined its efficacy in enhancing learning experiences, improving adherence to protocols and improving learning satisfaction levels in various nursing procedures (Anderson et al., 2021; Menon et al., 2022; García-Pazo et al., 2023). These findings draw attention to the transformative potential of AR in revolutionising ICU clinical practice training. Although few of the included studies exhibited statistically significant differences in the effectiveness of AR application in enhancing knowledge, skills and performance, this may be attributed partially to the limited sample size and the development of the prototype of the AR course. Comparably, Wüller et al., (2019) conducted a scoping review to identify the use of AR in general nursing education and uncovered that current studies mainly focus on evaluating the prototypes using pilot designs, which is inconsistent with our findings. However, it is noteworthy that most participants expressed positive views on using AR, like more helpful in identifying landmarks and visualisation of internal structures (Aebersold et al., 2018), as well as being interactive and novel (Anderson et al., 2021; Liang et al., 2021; Bliss et al., 2022), suggesting its potential to enhance knowledge acquisition and clinical skills training in ICU settings, particularly in learning complex content. While overall knowledge and skill performance scores did not differ significantly, AR fostered greater independence, reduced the need for instructor intervention during training and facilitated adherence to procedural guidelines (Aebersold et al., 2018; Heo et al., 2022).

Moreover, the findings of this review give emphasis to the paucity of literature regarding the usation of AR in ICU nurse education, suggesting that research in this area is still in its nascent stages. This finding is consistent with a recent scoping review of VR applications in ICU training (Hill et al., 2023). This dearth of evidence highlights the critical need for further investigation into the potential of AR to transform ICU nursing education. Our review revealed a significantly higher level of user experience and satisfaction among learners with AR-based training, which might be echoed in future ICU nursing education. Future studies should prioritise expanding on this emerging field, delving deeper into investigating the effectiveness of various AR tools and platforms for different training objectives in the ICU and measuring the impact of AR-based training on knowledge acquisition, skill development and clinical performance in novice ICU nurses. Another significant limitation of the current research is the lack of a clearly defined theoretical framework for evaluating AR simulations. This absence makes it challenging to interpret AR applications' effectiveness and evaluate findings across studies. It also hinders the design, implementation and evaluation of AR education. A well-defined theoretical framework should consider the unique characteristics of AR simulation, such as fidelity, immersion and interactivity and how these factors influence learning outcomes. Existing educational theories, such as the NLN/Jeffries Simulation Theory, could be adapted and applied to the evaluation of AR simulations (Cowperthwait, 2020).

Furthermore, the comprehensiveness of training contents represents a critical concern of ICU nurse education. This review found that mechanical ventilator operation was a frequently occurring training skill; it is essential to recognise that the scope of competencies required in ICU extends far beyond ventilator operation. Indeed, ICU nurses must possess proficiency in a multitude of skills spanning various aspects of patient care and medical interventions. Consequently, it is imperative to recognise the vast range of skills essential for effective ICU nursing practice, ranging from airway management, wound care, cardiovascular monitoring and renal replacement care to fundamental primary nursing care. However, the current body of literature appears to offer limited coverage of these diverse skills. Considering this gap, educators and health providers should endeavour to explore the range of skills essential for ICU nurse training. By addressing these research gaps, we can gain a more comprehensive understanding of how AR can be leveraged to optimise ICU nurse training, ultimately enhancing patient safety and improving outcomes in this critical care setting.

4.1. Implications and future direction

High-quality ICU nursing education is crucial for patient care. AR offers a compelling approach to enhance training in this complex environment. AR provides immersive learning experiences, allowing students to practice critical skills and decision-making in a safe, simulated setting. By using AR, students gain hands-on experience with complex equipment and procedures without real-world risks, mitigating the potential for serious errors. Additionally, AR promotes knowledge retention and application through engaging 3D visualisations of anatomy, medical devices and patient data, bridging the gap between theory and practice (Alismail et al., 2019; Ingrassia et al., 2020). The EDUCAUSE Horizon Report: 2019 Higher Education Edition, published by the Department of European Projects of the National Institute of Educational Technologies and Teacher Training, identifies AR as one of six emerging technologies poised to significantly impact higher education (Pelletier et al., 2022). The widespread adoption of mobile devices among university students facilitates the rapid dissemination of AR-based didactic content and promotes its integration into the classroom (Pelletier et al., 2022). Moreover, Microsoft HoloLens is an AR device worn on one's head and is becoming popular (Vidal-Balea et al., 2020) and the see-through holographic computer allows one to view high-definition holograms in his or her learning space. As the healthcare industry continues to evolve, integrating AR in nursing education for ICU settings can be a powerful tool in preparing the next generation of skilled and confident nurses, ultimately contributing to improved patient outcomes and enhanced quality of care. While AR technologies like Microsoft HoloLens, smartphones or tablets offer promising capabilities and are recognised as impactful emerging technologies, technical challenges such as slow response times and device compatibility issues (e.g., with smartphones) can hinder the learning experience (Garrett et al., 2015). Addressing these challenges is essential to maximise the effectiveness of AR in intensive care nursing education.

4.2. Limitations

First, very few studies investigated the application of AR in intensive care nursing education. Our results were confronted by the scarcity of limited research in ICU settings. In addition, the studies included in this review did not undertake a quality assessment as it is optional for scoping review per JBI guidelines (Peters et al., 2020). This review was conducted through a multidisciplinary search combining grey literature search; this enhanced the robust search for mapping the relevant literature. However, due to the limitation, only English articles were included in the final analysis, causing the selection bias. Another limitation was that AR application was mostly employed on a small scale and used a variety of programs in the included studies, making it hard to synthesise and compare the results.

5. Conclusion

In summary, the use of AR in nursing education is usable and feasible. Its use as an educational tool improves satisfaction, confidence and self-efficacy; AR can also promote the learning experience and increase realism in nursing education despite its scarcity in intensive care settings. The review provides an analysis of the most frequently used hardware and software for AR, which might be helpful for nursing educators in instructional planning. While this review highlights the promising applications of AR in ICU nursing education, a notable gap exists in the literature regarding the theoretical underpinnings of simulation evaluation. Future research should prioritise developing and testing robust theoretical frameworks to guide the assessment of AR simulation effectiveness. Future research could explore the use of AR in the ICU and comprehensively embrace a wide range of intensive care skills. To reduce learning disturbance, caution should be taken regarding AR devices' compatibility, fluidity and timeliness. Future studies should include the theoretical framework of simulation evaluation for developing and applying diverse simulation scenarios and building systematic, evidence-based nursing educational programs.

Ethical approval

Not applicable

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CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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