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Literature Review

Virtual reality in undergraduate and postgraduate nursing education: A scoping review integrating data mining for topic discovery

Silvia Ronchi[1], Rosario Caruso[2,3*], Diletta Fabrizi[1], Michela Luciani[1], Celeste M. Alfes[4], Noriyo Colley[5], Arianna Magon[6], Gianluca Conte[6], Anna Valli[7], Stefano Terzoni[2], Silvia Cilluffo[2], Maura Lusignani[2], Davide Ausili[1]

[1] *Department of Medicine and Surgery, University of Milano-Bicocca, Milano, Italy*
[2] *Department of Biomedical Sciences for Health, University of Milan, Milan, Italy*
[3] *Health Professions Research and Evidence Transfer Unit, IRCCS MultiMedica, Milan, Italy*
[4] *Frances Payne Bolton School of Nursing, Case Western Reserve University, Cleveland, USA*
[5] *Department of Health Sciences, School of Medicine, Hokkaido University, Sapporo, Japan*
[6] *Health Professions Research and Development Unit, IRCCS Policlinico San Donato, San Donato Milanese, Italy*
[7] *Mosaic Factor, Barcelona, Spain*

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ABSTRACT

Objectives: To map and critically analyze the evolution, scope, and characteristics of virtual reality (VR) applications in undergraduate and postgraduate nursing education.
Design: Scoping review, reported following PRISMA-ScR guidelines.
Data sources: PubMed, CINAHL, Scopus, and Embase were systematically searched up to April 2025, complemented by Google Scholar and reference screening.
Review methods: Eligible records were screened independently by two reviewers. Data were extracted across study characteristics, educational contexts, technologies, and outcomes. Narrative synthesis was combined with lexicometric and topic-modeling analyses to identify thematic and temporal trends.
Results: A total of 169 studies (2010–2025) were included. Publications increased sharply after 2020, shifting from procedural training toward learner-centered and competence-based education. Immersive VR via head-mounted displays was the most prevalent (70.4%), spanning from cardiopulmonary resuscitation to soft skills. Meta-analysis overlap was low, indicating methodological heterogeneity. Six major themes were identified, reflecting a transition toward holistic, reflective, and experiential learning frameworks.
Conclusions: VR in nursing education has matured conceptually but remains fragmented. Standardized outcomes, theory-driven frameworks, and equitable global adoption are needed to maximize its pedagogical potential.

Introduction

Virtual Reality (VR) represents an expanding frontier in health professions education, offering immersive and interactive learning experiences that reproduce complex clinical scenarios within controlled digital environments (Foronda et al., 2020). VR enables experiential learning, fosters skill retention, and promotes both cognitive and psychomotor competence development by engaging learners in simulated situations that closely mirror real-world contexts (Ma et al., 2024). In nursing education, the adoption of VR technologies supports the acquisition of technical procedures such as assessment, medication administration, and emergency response, while simultaneously enhancing non-technical competencies including communication, teamwork, and decision-making (Cant et al., 2022). This dual focus aligns with contemporary pedagogical paradigms that emphasize competency-based education and active learning approaches, positioning VR as a tool capable of bridging the gap between theoretical instruction and clinical practice (Plotzky et al., 2021).

Over the past decade, the evolution of hardware, software, and network infrastructures has expanded the feasibility and fidelity of VR-based learning experiences in nursing and allied health disciplines (Jans et al., 2023). Initially considered a niche innovation, VR has progressively become a strategic component of simulation-based education, particularly as advances in computing power and user interfaces have reduced costs and increased accessibility (Foronda

*Corresponding author.
E-mail address: rosario.caruso@unimi.it (R. Caruso).

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et al., 2020). The COVID-19 pandemic further accelerated this transformation by disrupting conventional clinical placements and prompting educators to seek alternative strategies for experiential learning (Vangone et al., 2024a, 2024b). In this context, VR emerged not merely as a technological surrogate for in-person training but as an adaptive educational environment capable of sustaining student engagement, continuity of learning, and clinical reasoning development during times of restricted physical interaction (Park et al., 2024; Vogelsang et al., 2024). The pandemic thus functioned as both a catalyst and a stress test for virtual learning ecosystems, revealing the potential of VR to complement and extend traditional pedagogical approaches in nursing education (Baysan et al., 2023).

It is important to distinguish, however, that the pandemic did not accelerate all forms of VR equally (Baysan et al., 2023). Non-immersive and semi-immersive modalities, such as desktop simulations, web-based platforms, and 360° video, expanded rapidly during COVID-19 because they could be deployed at scale with minimal equipment and were compatible with remote learning infrastructures (Vangone et al., 2024a, 2024b). Conversely, the adoption of fully immersive systems using head-mounted displays (HMDs) accelerated at a slower but still notable pace, mainly in institutions with existing simulation capacity or the ability to invest in specialized hardware (Jans et al., 2023). These modality-specific trajectories highlight how the pandemic influenced the diffusion of VR, with non-immersive solutions addressing immediate continuity-of-learning needs (Tene et al., 2024). At the same time, immersive HMD-based VR advanced as programs sought to restore experiential fidelity and learner engagement within hybrid and post-pandemic curricula (Russo, 2025).

The term VR encompasses a broad spectrum of computer-mediated environments that vary in their level of immersion, interactivity, and sensory feedback. These range from non-immersive desktop simulations, which use standard monitors and input devices to facilitate procedural training, to semi-immersive systems that combine panoramic screens and motion tracking, and fully immersive HMDs such as Oculus Quest, HTC Vive, or Meta XR that allow 360-degree navigation within virtual spaces (Park et al., 2024; Vogelsang et al., 2024). At higher levels of technological complexity, multi-user environments such as Cave Automatic Virtual Environment (CAVE) systems and networked collaborative simulations enable simultaneous participation of learners and instructors, supporting scenario-based teamwork training and interprofessional collaboration (Lo et al., 2025). Beyond these, hybrid and extended-reality (XR) platforms, integrating haptic feedback, motion sensors, or artificial-intelligence-driven scenarios, have expanded the possibilities of experiential learning by reproducing not only visual but also tactile and affective dimensions of care (Obeid et al., 2025). Within nursing education, such systems have been applied across diverse pedagogical domains, including psychomotor skill acquisition, emergency response, mental-health communication, ethical decision-making, and leadership development, demonstrating VR's adaptability to both undergraduate and postgraduate contexts (Vogelsang et al., 2024).

Despite rapid uptake, the evidence base on VR in nursing education remains fragmented across modalities, learner levels, and outcome domains (Zhao et al., 2022). Prior reviews have often examined specific slices of the field, such as immersive HMDs in pre-licensure education or single pedagogical purposes, while overlooking non-immersive and semi-immersive systems, postgraduate and continuous professional development (CPD) contexts, and interprofessional applications (Cant et al., 2022; Cho & Kim, 2024; Fealy et al., 2019; Foronda et al., 2020; Hou et al., 2025; Huai et al., 2024; Jans et al., 2023; Kim & Park, 2024; Moyer, 2023; Plotzky et al., 2021; Shorey & Ng, 2021; Vogelsang et al., 2024). As a result, comparable outcomes are measured with heterogeneous instruments, effect estimates are difficult to situate across settings, and decision-makers lack a consolidated view of where VR adds distinct value versus where it is merely substitutable within a broader simulation ecosystem. Moreover, secondary syntheses thus far have not interrogated redundancies among primary studies included in multiple meta-analyses, which limits our understanding of the true evidential breadth versus recirculated findings. Additionally, they do not leverage data-driven approaches to reveal latent topic structures and temporal shifts in emphasis. This combination of scope narrowness and low cumulative transparency constrains curriculum design, procurement choices, and research prioritization.

For these reasons, this scoping review aimed to systematically map the existing literature on VR in undergraduate and postgraduate nursing education, encompassing the full spectrum of technological immersion, from non-immersive to fully immersive systems, and the diverse pedagogical purposes they serve. The review sought to clarify how VR has been conceptualized, implemented, and evaluated across educational contexts by integrating traditional evidence mapping with advanced data-driven techniques. In particular, the analysis explored overlaps among primary studies included in secondary literature to identify redundancies and gaps, while the application of topic modeling enabled the identification of latent thematic structures and temporal trends within the field. Through this dual approach, the review provides a comprehensive and transparent overview of current knowledge, delineates emerging research priorities, and offers educators, researchers, and policymakers a strategic evidence base for guiding the integration and future development of VR in nursing education.

Materials and Methods

Design

This study is a scoping review conducted according to the methodological framework of the Joanna Briggs Institute (JBI) and reported following the PRISMA extension for Scoping Reviews (PRISMA-ScR) checklist (JBI, 2020; Tricco et al., 2018).

Research Questions

The main research question was defined using the Population–Concept–Context (PCC) framework to guide the review (Peters et al., 2021): "What is the current state of the literature on the use of virtual reality in undergraduate and postgraduate nursing education?"

According to the study protocol (Ronchi et al., 2025), to address this general aim, several sub-research questions (RQ) were formulated to explore the breadth and depth of the topic: (RQ1) In which geographical contexts has VR been used in nursing education? (RQ2) In what clinical or organizational settings has VR been implemented? (RQ3) What types of studies and syntheses have been produced? (RQ4) For which outcomes has VR been applied, and with what reported effects? (RQ5) What is the degree of overlap among primary studies included in existing reviews? (RQ6) What advantages and disadvantages of VR-based learning have been reported? (RQ7) What technologies or levels of immersion are most frequently employed? (RQ8) What emerging topics and trends can be identified through data-mining analyses? (RQ9) Are particular themes or applications associated with specific publication periods or settings?

Eligibility Criteria

In accordance with the JBI guidance, the eligibility criteria were defined using the PCC framework (Peters et al., 2021). This scoping review included all studies conducted within nursing education

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settings, without restrictions on geographic area, educational level, or year of publication. The Population comprised undergraduate nursing students and postgraduate registered nurses participating in formal educational or training programs. The Concept referred to the use of VR technologies, encompassing immersive, semi-immersive, and non-immersive modalities, applied to teaching, learning, or skill development in nursing education. The Context encompassed all academic, clinical, or simulated learning environments where VR was used as a pedagogical or assessment tool.

To ensure a comprehensive and inclusive synthesis, studies were included regardless of their methodological design. Empirical studies (quantitative, qualitative, or mixed methods), literature reviews, theoretical papers, commentaries, editorials, conference proceedings, dissertations, and policy documents were all eligible for inclusion if they met the PCC criteria. Publications focusing exclusively on the use of VR for patient education rather than nursing education were excluded, as were those that focused solely on determining information regarding device performance with no educational component significant to nursing.

No limits were imposed on publication year or country. However, for accessibility and linguistic consistency, only studies available in English, Italian, or Spanish, or those with an HTML version suitable for accurate automated translation, were included. Records without an accessible HTML format were excluded, as this would have precluded reliable assessment of their eligibility and content relevance.

Search Strategy

The detailed search strategy and queries are published in the study protocol (Ronchi et al., 2025). Briefly, potentially relevant records were identified through systematic searches of PubMed, Scopus, CINAHL, and EMBASE databases (last searches were performed on 30 September 2025). The search combined controlled vocabulary terms (e.g., MeSH, Emtree) and free-text keywords using Boolean operators to capture studies related to virtual reality and nursing education. The PubMed strategy was developed first and then adapted for the other databases to ensure consistency in terminology and scope. To ensure comprehensive coverage, supplementary searches were conducted on Google Scholar and through manual screening of the reference lists of included articles. The databases were re-searched before data extraction to capture the most recent publications. All retrieved records were imported into Zotero and Rayyan software for management, deduplication, and screening. Two independent reviewers performed title, abstract, and full-text screening according to the predefined inclusion and exclusion criteria. Disagreements were resolved by discussion or, when necessary, by consultation with a third reviewer. Reasons for exclusion at the full-text stage were systematically documented to ensure transparency and reproducibility.

Data Extraction

Data were extracted independently by two reviewers using standardized instruments developed for this review (Ronchi et al., 2025). The extraction forms (Supplementary File 1, Tables S1–S2) were created in Microsoft Excel and included key variables grouped under the following domains: (1) bibliographic information (author, title, year of publication, and country); (2) study design or synthesis method; (3) aim and research focus; (4) population and sample characteristics; (5) educational context (geographical area, clinical or academic setting, or simulated scenario); (6) technological concept (type of VR system, level of immersion, hardware/software used); (7) outcomes; (8) advantages and disadvantages; and (9) key findings.

The extracted data were used to generate a textual corpus that supported both narrative synthesis and lexicometric analysis. For the subset of secondary studies (systematic reviews and meta-analyses) addressing the efficacy of VR, a dedicated template (Supplementary File 1, Table S3) was applied to record all primary studies cited.

Data Analysis

Detailed analytical procedures are described in the published protocol (Ronchi et al., 2025). Data extracted from Tables S1–S2 were analyzed using a mixed narrative and computational approach. A narrative synthesis was used to address the primary research questions (RQ1–RQ7, excluding RQ5). Descriptive mapping summarized study designs, geographic and educational contexts, VR technologies, and outcome domains. The data contained in the Context, Study design, Concept, Outcomes, and Pros and Cons fields were systematically reviewed to identify recurrent themes, reported advantages, and implementation challenges across educational levels.

For RQ5, which examined redundancy among existing meta-analyses, overlap of primary studies was quantified using the Corrected Covered Area (CCA) metric, defined as (Kirvalidze et al., 2023):

$$\mathrm{CCA} = \frac{N_r - N_s}{N_s(N_p - 1)} \quad (1)$$

where *Nr* is the total number of primary study inclusions in meta-analyses on the same outcome (counting duplicates), *Ns* is the number of unique primary studies, and *Np* is the number of meta-analyses.

CCA is interpreted with conventional bands: 0–5% (low), 6–10% (moderate), 11–15% (high), >15% (very high) (Kirvalidze et al., 2023); it is undefined when *Np* = 1. Starting from CCA, to assess completeness, we also calculated review-level coverage for each meta-analysis as $|Sp|/|U|$, where $|Sp|$ is the number of unique primary studies included by that meta-analysis and $|U|$ is the union of unique primary studies across all meta-analyses for that outcome. In other words, coverage was the proportion of the available primary evidence captured by each meta-analysis relative to the total pool of unique primary studies across all meta-analyses investigating the same outcome, and it was summarized by median and interquartile range (IQR).

Before proceeding with automated text-mining procedures, a narrative content analysis was conducted on the extracted data to identify meaningful conceptual patterns across the included studies. Three hierarchical levels of thematic categorization were derived inductively from the “Concept” and “Outcomes” columns of the extraction matrix. This process allowed the organization of studies into progressively specific categories, reflecting Level 1 macro-domains, Level 2 sub-domains, and Level 3 specific themes, corresponding to broad educational or clinical outcome areas, discipline-specific competencies, and individual learning foci, respectively. The resulting framework provided a structured overview of the corpus and served as an intermediate analytical layer bridging the qualitative synthesis and computational modeling.

To address RQ8–RQ9, a lexicometric and topic-modeling analysis was performed on the textual corpus derived from the “Key Findings” field of all included studies. The text was preprocessed through tokenization, stopword and punctuation removal, and stemming. Summary indicators (total tokens, vocabulary size, hapax legomena, and type–token ratio) were computed to describe corpus richness. The cleaned corpus was then analyzed using Latent Dirichlet Allocation (LDA), a probabilistic topic-modeling method that detects latent thematic structures based on word co-occurrence patterns, according to previously published scoping reviews employing this analytical approach (Bozzetti et al., 2025; Caruso et al., 2025).

The optimal number of topics was determined by comparing model quality across four standard performance metrics, Griffiths2004 (model fit), CaoJuan2009 (topic coherence), Arun2010

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(topic distinctiveness), and Deveaud2014 (entropy-based stability), and refined through Bayesian optimization of hyperparameters (Arun et al., 2010; Cao et al., 2009; Deveaud et al., 2014; Griffiths & Steyvers, 2004). The resulting topics were assessed based on topic-term matrices and interpreted qualitatively to ensure conceptual coherence and relevance to the review's aims.

Quality Appraisal

Consistent with the methodological purpose of a scoping review, no formal quality appraisal of included studies was undertaken (Peters et al., 2021). As specified in the study protocol, we evaluated the feasibility of conducting a critical appraisal; however, due to the substantial methodological heterogeneity of the included evidence, such an assessment was deemed not appropriate for this review.

Results

Study Selection

The database search identified a total of 2,629 records: PubMed (n = 478), CINAHL (n = 722), Embase (n = 565), and Scopus (n = 864). After removing 1,181 duplicates, 1,448 records were screened by title and abstract. Of these, 1,222 records were excluded because they were study or review protocols (n = 17), focused on VR applications for patient or caregiver education (n = 69), or were unrelated to nursing education (n = 1,136). The full text of 226 reports was assessed for eligibility, and 57 were excluded for the following reasons: data on nurses or nursing students not isolable (n = 18), design or development papers without educational data (n = 22), or VR not representing the primary study focus (n = 17). All full texts were retrievable. A total of 169 studies met the inclusion criteria and were included in the final synthesis (Fig. 1).

Study Characteristics

A total of 169 studies (2010–2025) were included. Publications accelerated sharply after 2020: 2010–2015: 4 (2.4%), 2016–2020: 17 (10.1%), and 2021–2025: 148 (87.6%).

By geographic region (RQ1), studies were distributed as follows: Asia – 69 (40.8%), North America – 30 (17.8%), Europe – 20 (11.8%), Middle East – 10 (5.9%), Africa – 1 (0.6%), Australia/Oceania – 3 (1.8%), and Mixed countries – 36 (21.3%). The label "Mixed countries" denotes studies authored by research teams including institutions from more than one world region, where no single geographical context could be assigned—for example, collaborations between Asian and European universities.

By World Bank income grouping (RQ1), most studies originated from high-income settings – 123 (72.7%), followed by upper-middle income – 9 (5.3%), lower-middle income – 1 (0.6%), and mixed-economy collaborations – 36 (21.3%).

Regarding the educational context (RQ2), most studies targeted undergraduate programs (141, 83.4%), followed by postgraduate (16, 9.5%) and mixed undergraduate/postgraduate (12, 7.1%).

Regarding publication type (RQ3), the vast majority were journal articles (162, 95.9%), with conference proceedings (4, 2.4%) and other types, such as book chapters (3, 1.8%).

For study design (RQ3), the distribution was: quasi-experimental – 61 (36.1%), literature review – 44 (26.0%), observational – 16 (9.5%), qualitative – 16 (9.5%), and other (multi-phase, mixed-methods, or feasibility studies) – 32 (18.9%).

For technology used (RQ7), immersive VR employing head-mounted displays predominated (119, 70.4%), followed by non-immersive/desktop VR (11, 6.5%), 360° video (7, 4.1%), web/mobile VR (8, 4.7%), XR/AR/MR (7, 4.1%), hybrid or multi-modal systems (8, 4.7%), and other technologies (9, 5.3%).

Comprehensive mappings of individual studies to each category, as well as the complete reference list, are provided in Table 1 and Supplementary File 1.

Thematic Categorization of Study Focus (RQ2, RQ4, RQ6–RQ7)

As depicted in Fig. 2, three Level-1 domains predominated: Clinical Outcomes/Competences accounted for 58.0% of studies, Generic Nursing Competences for 24.9%, and Methodological/Meta-educational Themes for 17.1%. Within Clinical Outcomes/Competences, studies frequently addressed procedural skills, acute and chronic care contexts, pediatric and mental-health nursing, infection prevention, and emergency/disaster preparedness; Generic Nursing Competences encompassed communication, empathy, critical thinking and judgment, leadership, and self-regulated learning; Methodological/Meta-educational Themes included evidence synthesis, simulation methodology, and evaluation approaches. This structured representation directly informs RQ2 by specifying clinical and organizational foci across undergraduate and postgraduate settings, advances RQ4 by consolidating outcome families and measurement emphases, and provides a basis for synthesizing reported advantages, disadvantages, and technology requirements pertinent to RQ6 and RQ7.

Temporal Evolution of Themes

To explore temporal dynamics (RQ9) in the development of VR applications within nursing education, a longitudinal mapping was performed linking the three-level thematic hierarchy (L1–L3) to the publication year of each study. As shown in Fig. 3, the evolution of research topics reflects a clear chronological stratification, illustrating how the thematic focus of VR-based education has expanded and diversified over time. During the early period (2010–2015), studies were predominantly focused on procedural and emergency-related training within the Clinical Outcomes/Competences domain, with an emphasis on technical skill acquisition and acute care simulations (e.g., CPR, airway management, neonatal care). From 2016 to 2020, the thematic spectrum broadened to include Generic Nursing Competences, such as communication and empathy, and Methodological/Meta-educational Themes, focusing on feasibility testing and usability of emerging VR platforms. Following 2020, which coincided with the pedagogical disruptions caused by the COVID-19 pandemic, the literature shifted markedly toward complex cognitive and affective domains, including critical thinking, leadership and diversity, self-directed learning, and patient-centered care, alongside a rise in evidence synthesis and meta-educational research.

The alluvial visualization highlights the progressive transition from task-oriented, procedural training to holistic and reflective learning frameworks, indicating an educational maturation of VR technologies in nursing. The increasing interconnection among domains over time also indicates that VR is now positioned not only as a tool for isolated skill practice but as a comprehensive pedagogical ecosystem supporting experiential, interprofessional, and person-centered learning approaches.

Textual Data Mining and Topic Identification

To ensure that the textual corpus was adequate for topic modeling, a preliminary lexicometric analysis was performed on the "Key Findings" field extracted from all included studies (n = 169). The corpus comprised 22,229 total word occurrences (N) and 3,444 unique forms (V), indicating sufficient lexical richness and variety to support stable topic detection. The number of hapax legomena (terms appearing only once) was 1,572, consistent with the technical and

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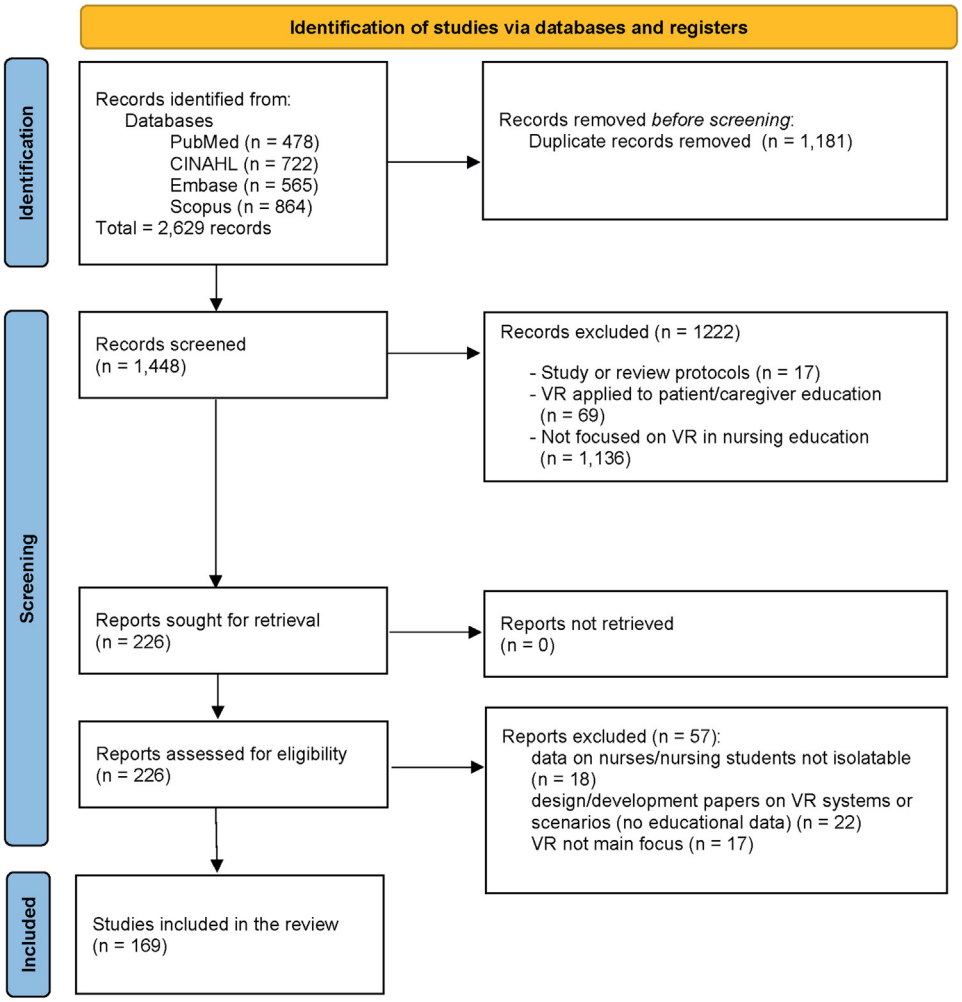

Fig. 1. PRISMA 2020 flow diagram.

specialized vocabulary typical of academic writing. Hapax words were retained for descriptive reporting but excluded from the final topic-modeling dataset to reduce lexical noise. The mean number of occurrences per text was 131.53, suggesting that each abstract or extracted section contained adequate semantic content for latent-structure estimation. The type–token ratio (V/N = 0.1549) reflected a balanced relationship between lexical repetition and diversity, ensuring that meaningful co-occurrence patterns could be identified without excessive redundancy or sparsity. Overall, these metrics confirm that the corpus meets standard quantitative thresholds for LDA, providing a sufficiently large, diverse, and semantically informative dataset for probabilistic topic modeling.

The detailed LDA preprocessing workflow and modeling parameters are reported in Supplementary File 1. After testing models with k ranging from 3 to 12, the six-topic solution (k = 6) was selected as the optimal balance between interpretability and thematic granularity, based on convergence of multiple quality metrics (Griffiths2004, Arun2010, CaoJuan2009, and Deveaud2014) and manual inspection of topic coherence.

Each topic was interpreted through the triangulation of top-terms, representative documents, and intertopic distance visualization (Fig. 4). The six resulting topics reflected coherent thematic areas across the corpus (Sievert & Shirley, 2014): (1) Effectiveness and Clinical Training—studies evaluating the efficacy of VR interventions in improving knowledge, performance, or satisfaction; (2) Effectiveness Assessment and Evaluation—systematic reviews, meta-analyses, and methodological research assessing outcomes and evidence synthesis; (3) User Experience, Empathy, and Competence—qualitative and mixed-method studies addressing learner engagement, empathy, and self-efficacy; (4) Procedural and Specialist Interventions—highly technical applications of VR for clinical or procedural skills (e.g., IV insertion, resuscitation, catheterization); (5) Communication and Curricula—interventions embedding communication, teamwork, and curriculum integration; (6) Procedural Skill Acquisition Processes and Approaches—pedagogical frameworks examining learning trajectories and instructional design in immersive VR training.

Across the 169 studies, 80 (47.3%) were categorized as Multiple topics, indicating that nearly half of the literature addressed overlapping domains such as skill performance, user perception, and learning outcomes simultaneously. Among single-topic classifications, the most frequent were Effectiveness Assessment and Evaluation (n = 27; 16.0%) and Effectiveness and Clinical Training (n = 22; 13.0%), followed by User Experience, Empathy, and Competence (n = 13; 7.7%), Procedural and Specialist Interventions (n = 9; 5.3%), Communication and Curricula (n = 9; 5.4%), and Procedural Skill Acquisition Processes and Approaches (n = 9; 5.3%). This distribution highlights the dual emphasis of VR research in nursing education, including the empirical evaluation of learning effectiveness and the exploration of experiential, humanistic, and curricular dimensions. These six computationally derived topics conceptually mirror the three macro-

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Table 1
Characteristics of the included documents (n = 169).

	Count (%)
Years of publication	
2010–2015	4 (2.4)
2016–2020	17 (10.1)
2021–2025	148 (87.6)
Geographic region	
Africa	1 (0.6)
Asia	69 (40.8)
Europe	20 (11.8)
Middle East	10 (5.9)
North America	30 (17.8)
Australia /Oceania	3 (1.8)
Not applicable	36 (21.3)
Country economy	
Lower middle income	1 (0.6)
Upper middle income	9 (5.3)
High income	123 (72.7)
Mixed economies	36 (21.3)
Type of publication	
Conference proceedings	4 (2.4)
Journal article	162 (95.9)
Other (chapters, books)	3 (1.8)
Study design	
Literature review	44 (26.0)
Quasi-experimental	61 (36.1)
Observational	16 (9.5)
Qualitative	16 (9.5)
Other (multi-phase, mixed-methos feasibility)	32 (18.9)
Educational context	
Undergraduate education	141 (83.4)
Postgraduate education	16 (9.5)
Mixed undergraduate & postgraduate	12 (7.1)
Technology used/investigated	
Immersive VR (HMD)	119 (70.4)
Non-immersive VR (desktop/screen-based)	11 (6.5)
360° Video-based VR	7 (4.1)
Web-based/Mobile VR	8 (4.7)
XR/AR/MR	7 (4.1)
Hybrid/Multi-modal VR	8 (4.7)
Other	9 (5.3)

Note: Full reference details for each category are available in Supplementary File 1.
HMD = head-mounted display; XR = extended reality; AR = augmented reality; MR = mixed reality.

domains identified through manual categorization, providing convergent validity between qualitative and quantitative analyses.

Temporal Evolution of Topics

The temporal distribution of topics derived from the LDA model revealed a clear and progressive diversification of the thematic landscape of VR-based nursing education over time (Fig. 5). In the early period (2010–2015), the literature was dominated by topics related to Effectiveness Assessment and Evaluation (Topic 2) and Effectiveness and Clinical Training (Topic 1), reflecting the initial focus on assessing feasibility and learning outcomes of early VR interventions. From 2016 to 2020, there was a gradual broadening of focus toward Procedural and Specialist Interventions (Topic 4) and Communication and Curricula (Topic 5), aligning with the expansion of immersive simulation environments and the increased curricular integration of VR technologies.

Following 2020, a marked acceleration in publication volume coincided with the pandemic-related transformation of educational delivery. During this period, topics reflecting User Experience, Empathy, and Competence (Topic 3) and Procedural Skill Acquisition Processes and Approaches (Topic 6) gained prominence, indicating a conceptual shift from outcome assessment to learner-centered design, affective engagement, and reflective practice. The growing presence of Multiple-topic classifications further underscores the increasingly interdisciplinary character of this field, where studies tend to address effectiveness, usability, and pedagogical design simultaneously.

The heatmap (upper panel) illustrates this transition quantitatively: the relative prominence of Topic 2 decreases over time, while Topics 3, 5, and 6 show steady growth, suggesting a pedagogical evolution from evaluation-driven research to competence- and experience-oriented inquiry. The stacked bar chart (lower panel) reinforces this interpretation, showing a sharp increase in both the volume and thematic diversity of publications after 2020, consistent with the post-pandemic acceleration of immersive and hybrid learning research.

Overlap Among the Subset of Included Meta-analyses

Across outcomes, overlap was generally low to moderate, indicating that the evidence base is fragmented rather than redundant. Moderate overlap was observed for Knowledge (CCA = 9.2%), Confidence (8.3%), and Skills (6.5%), whereas Satisfaction (4.8%) showed low overlap.

Complementary coverage analysis, defined as the proportion of unique studies included in each meta-analysis relative to the total pool for that outcome, confirmed this pattern of dispersion. For outcomes with multiple meta-analyses, the median coverage was 20.6% for Knowledge (IQR = 11.8–22.1), 21.7% for Skills (17.4–26.1), and 14.3% for Satisfaction (12.5–23.2), implying that each review captures only a fraction of the available evidence. When exactly two meta-analyses were present, such as for Confidence or Self-efficacy, median coverage hovered around 50%, reflecting partial complementarity rather than redundancy. Details are provided in Supplementary File 1.

Discussion

This scoping review was undertaken to systematically map and critically examine the breadth, characteristics, and evolution of VR applications in undergraduate and postgraduate nursing education. Despite the growing body of literature on immersive learning, prior reviews have largely focused on single competencies, specific technologies, or limited time frames, leaving an incomplete picture of how VR has transformed nursing pedagogy over the past decade (Cant et al., 2022; Cho & Kim, 2024; Fealy et al., 2019; Foronda et al., 2020; Hou et al., 2025; Huai et al., 2024; Jans et al., 2023; Kim & Park, 2024; Moyer, 2023; Plotzky et al., 2021; Shorey & Ng, 2021; Vogelsang et al., 2024). This study integrated narrative synthesis, bibliometric mapping, and data-mining analyses, providing a comprehensive and temporally sensitive overview of the field. The findings reveal a rapid post-2020 expansion in both the volume and conceptual sophistication of VR-based interventions, marking a shift from early procedural and task-oriented simulations toward holistic, learner-centered, and competence-oriented educational approaches. Overall, the results demonstrate that VR is no longer merely a technological adjunct for clinical skills training but a dynamic pedagogical environment that fosters the cognitive, affective, and interprofessional dimensions of nursing competence.

Pedagogical Evolution of VR in Nursing Education

The temporal and thematic analyses collectively illustrate a clear pedagogical evolution in how virtual reality has been conceptualized and employed within nursing education. In its early phase (2010–2015), VR served primarily as a procedural simulation tool, reproducing controlled environments for task-oriented training such as resuscitation, airway management, or infection control (Jung et al., 2012; Kilmon et al., 2010; Vidal et al., 2013; Yang & Ma, 2013). These

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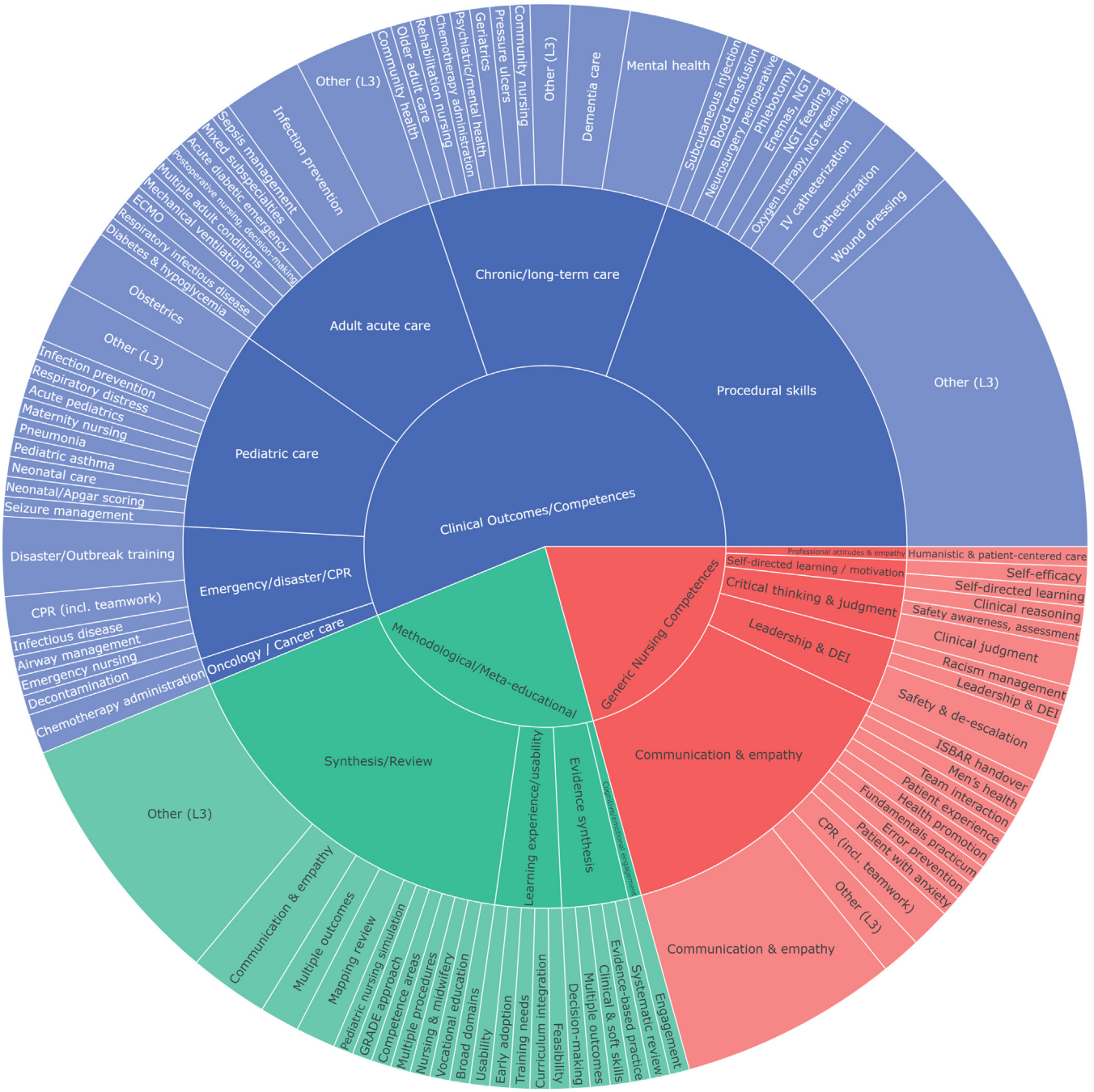

Fig. 2. Hierarchical thematic categorization of virtual reality applications in nursing education. Note: The Sunburst chart visualizes the three-level hierarchical structure derived from the narrative content analysis of included studies (n = 169). The inner ring (Level 1) represents the three macro-domains—Clinical Outcomes/Competences (blue), Generic Nursing Competences (red), and Methodological/Meta-educational Themes (green). The middle ring (Level 2) displays sub-domains within each macro-domain (e.g., Procedural skills, Communication and empathy, Evidence synthesis), while the outer ring (Level 3) specifies detailed topics or specific areas of educational focus (e.g., Mental health, Leadership and Diversity, Equity, and Inclusion (DEI), Simulation methodology). The relative segment size reflects the proportional frequency of each category across the included studies. This visualization provides an integrated overview of the conceptual diversity and thematic distribution of VR-based educational interventions in nursing.

interventions emphasized psychomotor accuracy and repetition, aligning with behaviorist traditions of skill acquisition.

During the middle phase (2016–2020), the pedagogical scope broadened: VR began to be integrated into curricular structures and applied to communication, empathy development, and clinical reasoning, reflecting a shift toward constructivist and experiential learning principles (Butt et al., 2018; Chen et al., 2020; Erlinger et al., 2019; Fealy et al., 2019; Smith et al., 2016, 2018). In the most recent phase (post-2020), catalyzed by the pedagogical disruptions of the COVID-19 pandemic, the literature reveals a marked expansion into complex cognitive and affective domains (i.e., critical thinking, leadership, self-directed learning, and diversity awareness) supported by hybrid and networked learning ecosystems (Hung et al., 2024; Jeong & Cha, 2024; Johnson et al., 2024; Jones et al., 2023).

This chronological progression mirrors broader transformations in simulation-based education across health professions, where VR has evolved from a technology for procedural reproduction to a medium for reflective, immersive, and learner-centered engagement. Consequently, nursing educators now employ VR environments as pedagogical mediators that make visible and reproducible the embodied

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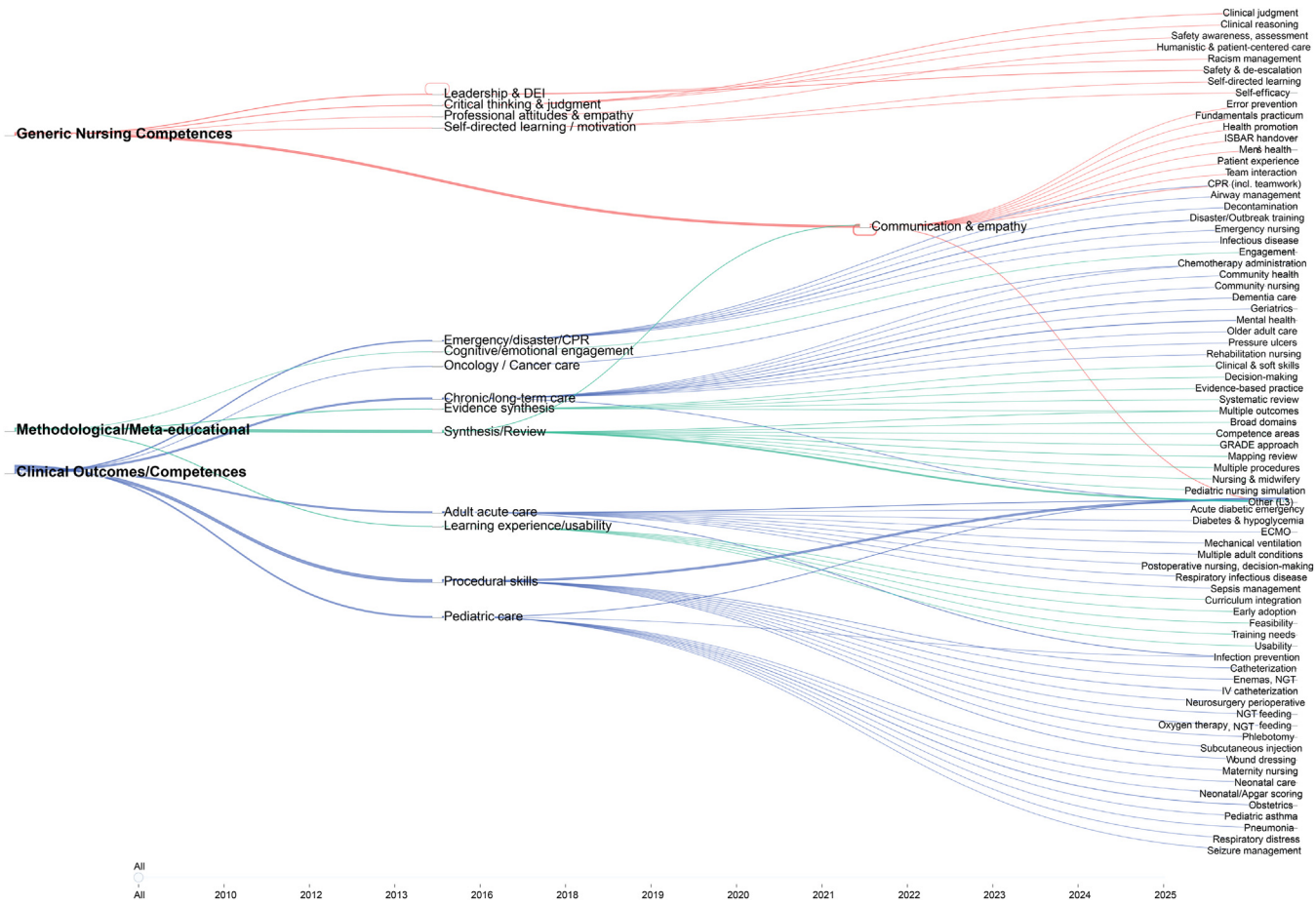

Fig. 3. Temporal evolution of thematic domains in virtual reality–based nursing education. Note: The alluvial (Sankey) diagram illustrates the temporal progression of themes (L1→L2→L3) across publication years (2010–2025). The width of each stream represents the relative frequency of studies addressing that sub-theme within a given period. The visualization highlights a chronological shift from early procedural and acute-care training toward broader cognitive, communicative, and methodological applications, reflecting the maturation and diversification of VR use in nursing education.

practices and situated reasoning once transmitted only through traditional on-the-job training. In doing so, they transform VR from a technical tool into a reflective space where the cognitive, emotional, and social dimensions of nursing competence can be explicitly modeled and taught.

Methodological Diversification and Limitations of Evidence

The methodological landscape of VR-based nursing education research demonstrates substantial diversification, reflecting both the dynamism and the developmental stage of this field. Early investigations predominantly employed quasi-experimental designs to demonstrate short-term improvements in knowledge, performance, or satisfaction following exposure to VR interventions (Jung et al., 2012; Kilmon et al., 2010; Vidal et al., 2013; Yang & Ma, 2013). Over time, methodological plurality has increased, encompassing qualitative explorations of user experience, mixed-methods evaluations of pedagogical integration, and a growing number of literature reviews and meta-analyses attempting to consolidate dispersed findings (Williams et al., 2020). However, the overlap analysis conducted among meta-analyses revealed only low to moderate redundancy, underscoring the conceptual heterogeneity and limited harmonization of outcome measures across studies.

This fragmentation, while indicative of innovation and methodological exploration, also reflects a lack of shared evaluation frameworks and standardized educational taxonomies. In this regard, none of the available meta-analyses can be considered comprehensive, as each addresses distinct subsets of outcomes or populations without integrating the full breadth of the evidence base. A meta-analysis of meta-analyses, supported by consistent outcome mapping and cross-study harmonization, could therefore help to clarify the cumulative effects of VR interventions and advance the synthesis of this expanding literature (Belbasis et al., 2022).

The predominance of quasi-experimental designs and scarcity of randomized controlled trials suggest that much of the existing evidence remains context-specific and not yet generalizable across nursing curricula or institutional settings (Kirvalidze et al., 2023; Zhao et al., 2022). To advance beyond this phase of methodological adolescence, future research must prioritize outcome standardization, such as through the application of competency-based learning frameworks or Kirkpatrick's evaluation levels, and promote the integration of nursing-specific conceptual models capable of linking immersive learning processes with measurable educational and clinical impacts (Huang et al., 2022).

Geographic and Socioeconomic Disparities

The geographic and socioeconomic distribution of the included studies reveals a pronounced imbalance in the development and evaluation of VR-based nursing education. The strong representation of high-income countries, particularly those in Asia, North America, and Europe, contrasts with the limited contribution from low- and

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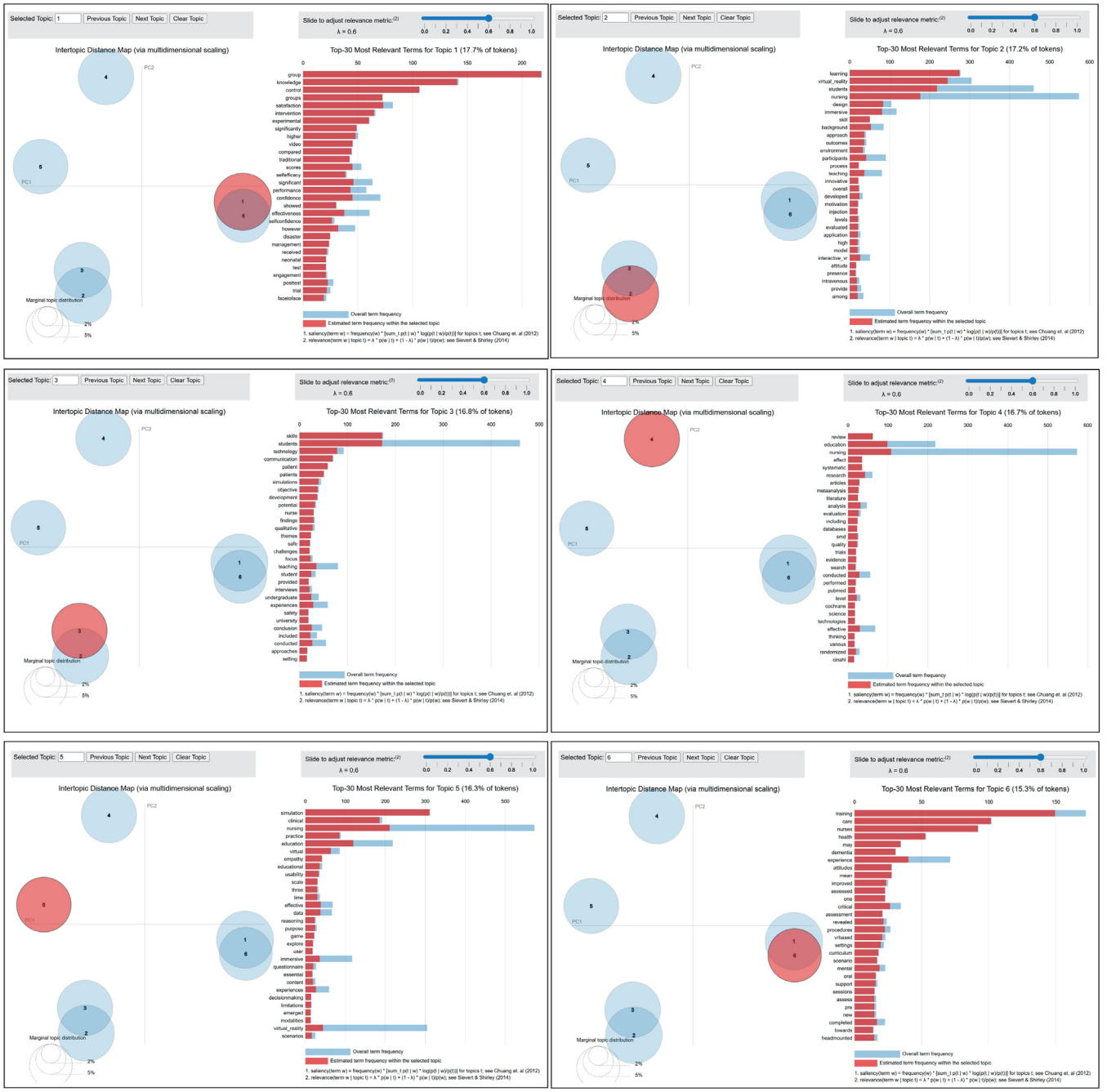

Note. Topic modeling was conducted using LDA with the λ (gamma) parameter set at 0.6 to balance interpretability and exclusivity of terms, as recommended by Sievert and Shirley (2014) in the LDAvis methodology. This choice facilitated topic labeling by ensuring that salient yet distinctive terms contributed to interpretation. The six topics were labeled as: (1) Effectiveness assessment & evaluation, (2) Effectiveness & Clinical Training, (3) User Experience, Empathy & Competence, (4) Procedural & Specialist Interventions, (5) Communication & Curricula, and (6) Procedural Skill Acquisition Process and Approaches.

Fig. 4. Topic modeling of virtual reality–based nursing education studies (LDA solution, k = 6). Note: Each panel displays an intertopic distance map (left) and the 30 most relevant terms (right) for one topic. Bubble size indicates topic prevalence; proximity reflects semantic relatedness. Top-terms, exemplar documents, and interactive inspection in LDAvis guided topic labeling. Topic modeling was conducted with $\gamma = 0.6$ to balance term exclusivity and interpretability (Sievert & Shirley, 2014).

middle-income regions, where only a handful of studies were identified (Belbasis et al., 2022). This asymmetry reflects persistent disparities in digital infrastructure, financial accessibility, and institutional readiness that constrain the adoption of immersive learning technologies. The cost of high-fidelity hardware, the need for specialized technical support, and uneven broadband availability continue to limit equitable access to VR-enhanced training across global nursing programs (Belbasis et al., 2022; Samson et al., 2025).

Moreover, most available interventions have been designed and tested within technologically advanced educational ecosystems, raising concerns about contextual validity and the cultural adaptability of pedagogical models developed in resource-rich environments. These factors risk reinforcing educational inequities rather than mitigating them if global dissemination proceeds without attention to contextual diversity. Notably, the presence of mixed-country collaborations, which involve studies co-authored by teams from different

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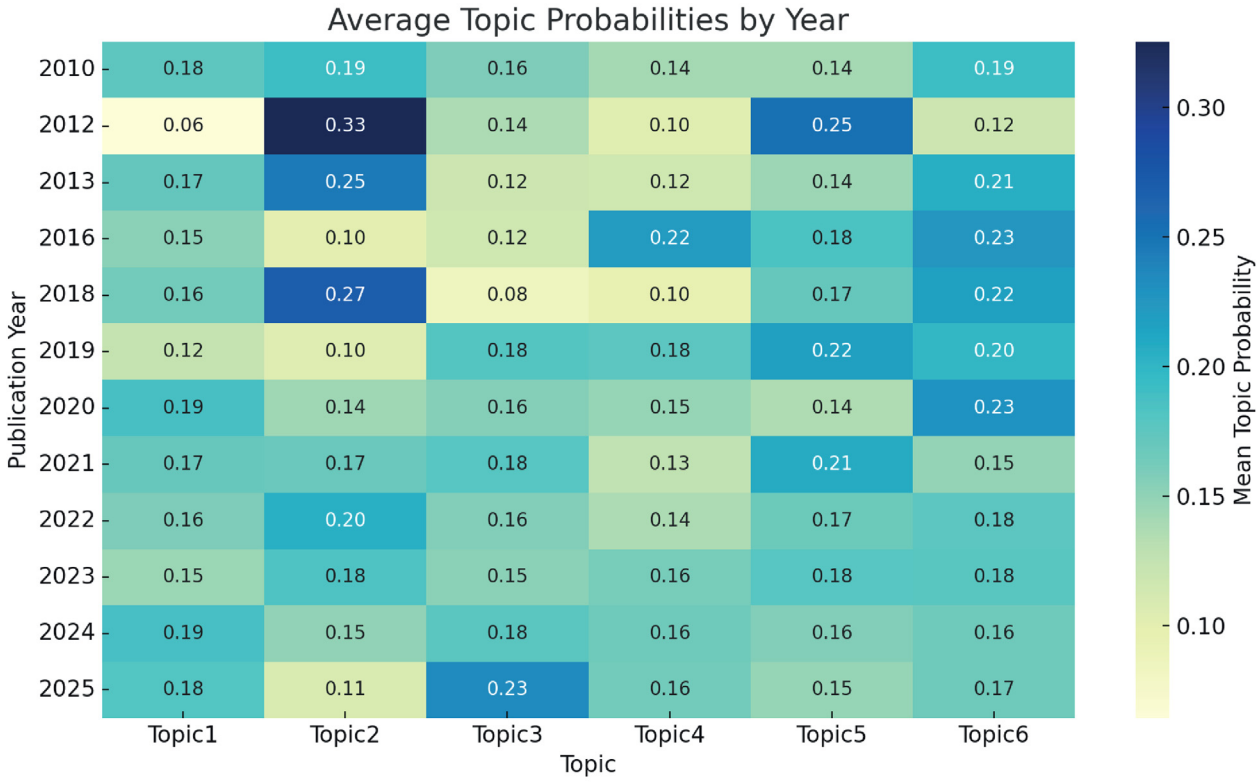

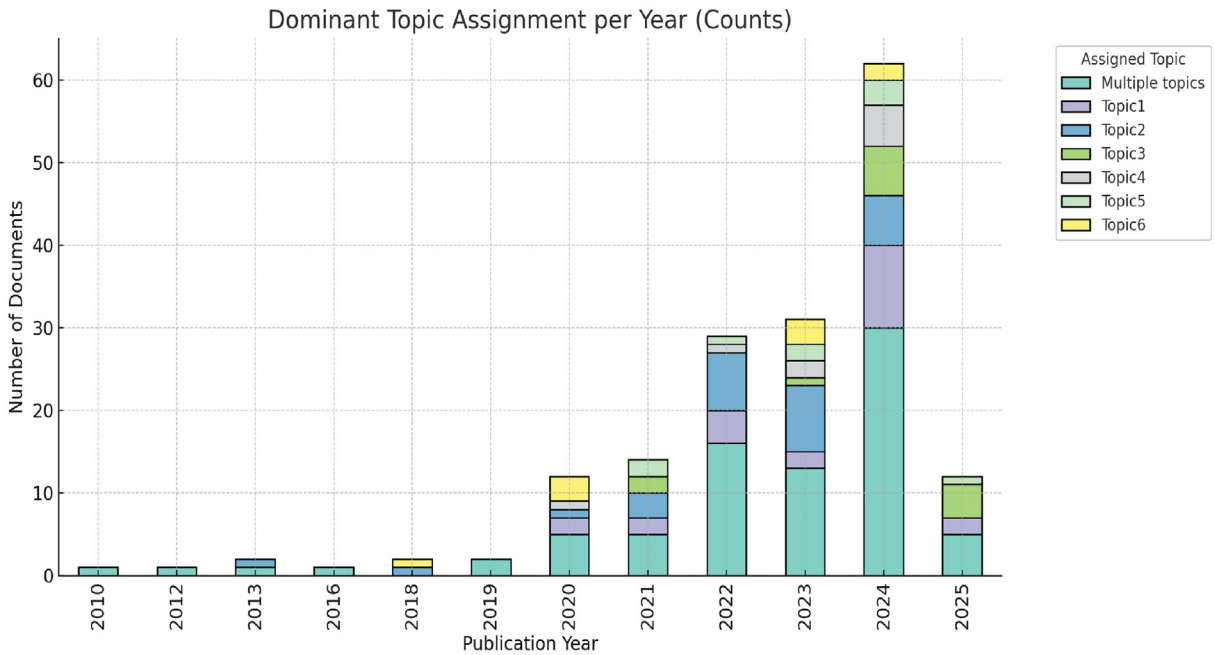

Topic 1: Effectiveness & Clinical Training
Topic 2: Effectiveness assessment & evaluation
Topic 3: User Experience, Empathy & Competence
Topic 4: Procedural & Specialist Interventions
Topic 5: Communication & Curricula
Topic 6: Procedural Skill Acquisition Process and Approaches
Multiple topics: Documents spanning multiple topics

Top chart (heatmap). The heatmap reports the average topic probabilities across years, weighted by document-level distributions. This probability-based approach avoids forcing a single assignment, capturing the nuanced contribution of multiple topics within the same document.

Bottom chart (stacked bar). The stacked bar chart shows the distribution of dominant topic assignments per year, where each document is attributed to the topic with the highest probability. This representation highlights the evolution of topic prevalence over time.

Fig. 5. Temporal evolution of topic prevalence in virtual reality–based nursing education. Note: The top panel (heatmap) displays the average topic probabilities across years, weighted by document-level distributions, thus capturing the contribution of multiple topics within each publication. The bottom panel (stacked bar chart) presents dominant topic assignments per year based on the highest posterior probability. Together, these plots reveal an increasing diversification and convergence of themes, reflecting the maturation of VR research from effectiveness testing toward holistic educational design and learner experience.

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economic or cultural settings, suggests a promising model for knowledge transfer and capacity building. Such partnerships can facilitate the adaptation of VR frameworks to diverse educational realities, promoting mutual learning and sustainability. Moving forward, equitable capacity-building in digital nursing education requires coordinated investment, open-access resources, and culturally responsive design principles to ensure that the benefits of immersive learning are globally shared rather than geographically concentrated (Tudor Car et al., 2022).

Technological Trends and Pedagogical Fit

The analysis of technology types confirmed a clear predominance of immersive VR delivered through HMDs, representing over two-thirds of the included studies. This technological choice reflects a growing recognition of the pedagogical value of immersion, presence, and interactivity in shaping learning experiences (Vangone et al., 2024a, 2024b). Immersive environments enhance perceptual realism and situational fidelity, allowing students to engage effectively with clinical scenarios and develop empathy toward patients, particularly in areas such as mental health, palliative care, and communication training. Empirical evidence suggests that immersion facilitates deeper cognitive processing and skill retention by stimulating emotional engagement and embodiment (Lin et al., 2024). However, this potential is not without limitations. High immersion may impose cognitive and sensory load, occasionally leading to motion sickness or distraction, especially when instructional scaffolding is insufficient. Cost and maintenance requirements further constrain scalability, particularly in resource-limited contexts (Belbasis et al., 2022).

The balance between immersion and cognitive manageability thus emerges as a critical pedagogical consideration, emphasizing that technological sophistication alone does not guarantee learning effectiveness. From an educational design perspective, the effectiveness of VR depends on the pedagogical fit, which refers to the degree to which the technology's affordances align with the intended learning outcomes (Boboc & Koç, 2019). For procedural skill acquisition, high-fidelity, sensorimotor-rich simulations may be optimal; for reflective or communicative competences, moderated immersion combined with guided debriefing may yield superior outcomes. This understanding signals a shift from viewing VR as an isolated tool to recognizing it as an adaptable pedagogical medium integrated within broader curricula. Looking forward, the field is moving toward hybrid XR ecosystems, where VR merges with augmented and mixed reality, and toward AI-driven adaptive simulations capable of personalizing learner trajectories (Li et al., 2025). Such systems promise to transform VR from a demonstration technology into an intelligent, evidence-informed learning environment, marking a maturation of both the technology and its educational philosophy.

Integrative Synthesis: Toward a Pedagogical Ecosystem

Taken together, the pedagogical, methodological, and technological dimensions revealed by this review delineate an educational landscape in transition. The evolution of VR-based nursing education cannot be fully understood through technology alone; its pedagogical value stems from the dynamic interplay between immersive design, theoretical foundations, and evaluative rigor. Studies that integrate experiential learning principles with methodologically sound assessment strategies demonstrate that immersion becomes educationally meaningful only when aligned with explicit competence frameworks and reflective practice (Arrigoni et al., 2017).

Conversely, where technological implementation precedes pedagogical intent, learning outcomes remain fragmented or narrowly operationalized. Rather than treating VR as an isolated instructional tool, current trends position it as a pedagogical ecosystem, a medium through which students are able to simultaneously acquire technical proficiency, humanistic competence, and reflective capacity within immersive, evidence-informed environments. This integrative evolution sets the theoretical foundation for the field's next phase of pedagogical and methodological maturity.

Implications for Education and Faculty Development

The findings of this review highlight a growing interest in VR as a complementary component within simulation-enhanced nursing education. However, the early stage of methodological development and the limited generalizability of the existing evidence require caution when formulating broad curricular recommendations. While VR has demonstrated potential across cognitive and psychomotor domains, the heterogeneity of study designs, outcomes, and evaluation frameworks suggests that its educational value remains context-dependent and not yet generalizable across curricula or institutional settings. Accordingly, rather than advocating for widespread or comprehensive curricular integration, current evidence supports a phased and pedagogically aligned introduction of VR (Li et al., 2025).

Educators and faculty developers may selectively adopt VR in areas where its affordances demonstrably enrich experiential learning, such as high-risk, low-frequency scenarios, communication training, or situated decision-making, and where it addresses logistical or resource constraints inherent to traditional simulation formats. This targeted approach aligns the technology's strengths with specific pedagogical needs while avoiding premature reliance on evidence that remains emergent (Caruso et al., 2018; Spada et al., 2022, 2023, 2025; Xharra et al., 2024).

Effective adoption also requires a parallel investment in faculty readiness and instructional capacity. Faculty benefit from structured preparation in scenario design, integration into existing curricular frameworks, technical troubleshooting, and evidence-informed debriefing methods that preserve educational rigor across varying levels of immersion. As more methodologically robust studies clarify when, for whom, and under what conditions VR yields unique learning gains, educators will be better positioned to make informed decisions regarding broader implementation. In this sense, VR should be regarded not as a fully established instructional standard but as a promising, evolving element within the broader simulation ecosystem, one that warrants continued evaluation, iterative refinement, and thoughtful pedagogical alignment as the field progresses toward greater conceptual and methodological maturity (Caruso et al., 2018; Spada et al., 2022, 2023, 2025; Xharra et al., 2024).

Strengths and Limitations

This scoping review is strengthened by its broad coverage across years, regions, educational levels, and technologies; the triangulation of manual thematic coding with computational topic modeling; and a transparent, published protocol that supports replicability. At the same time, several limitations of scope should be acknowledged. Although we included studies in multiple languages, a subset required automated or summary-level translation, which may introduce minor semantic drift or terminology inconsistencies at the margins. Consistent with the aims of a scoping approach, no formal critical appraisal was undertaken; the goal was to map and characterize, not to adjudicate effect sizes or methodological quality. Finally, topic-model results are contingent on preprocessing and parameter choices, which we mitigated through sensitivity checks.

Conclusions

This scoping review provides the most comprehensive synthesis to date of virtual reality applications in nursing education, revealing

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a rapid post-2020 expansion in both scope and conceptual sophistication. The field has evolved from isolated, procedural simulations to immersive, learner-centered, and competence-oriented educational ecosystems that integrate cognitive, affective, and interprofessional dimensions of learning. Yet, despite this maturation, methodological fragmentation and unequal global representation persist, limiting the comparability and transferability of evidence. Future research should advance beyond proof-of-concept studies toward theory-driven, equity-informed, and outcome-harmonized approaches that consolidate standards, foster cross-context collaboration, and fully realize VR's pedagogical and transformative potential in nursing education.

Ethical Approval

This study did not involve human participants or animals and therefore did not require ethical approval. All data analyzed were obtained from publicly available literature.

Data Availability Statement

The datasets generated and analyzed during the current study, including the extraction forms and topic modeling outputs, are available from the corresponding author on reasonable request. Supplementary materials include detailed data extraction tables and analytical parameters.

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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.

CRediT authorship contribution statement

Silvia Ronchi: Writing – original draft, Visualization, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rosario Caruso:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Diletta Fabrizi:** Writing – review & editing, Writing – original draft, Conceptualization. **Michela Luciani:** Writing – review & editing, Writing – original draft, Conceptualization. **Celeste M. Alfes:** Writing – review & editing, Writing – original draft, Conceptualization. **Noriyo Colley:** Writing – review & editing, Writing – original draft, Conceptualization. **Arianna Magon:** Writing – review & editing, Supervision, Data curation, Conceptualization. **Gianluca Conte:** Writing – review & editing, Supervision, Data curation, Conceptualization. **Anna Valli:** Writing – review & editing, Writing – original draft, Conceptualization. **Stefano Terzoni:** Writing – review & editing, Writing – original draft, Conceptualization. **Silvia Cilluffo:** Writing – review & editing, Writing – original draft, Conceptualization. **Maura Lusignani:** Writing – review & editing, Writing – original draft, Conceptualization. **Davide Ausili:** Writing – original draft, Supervision, Methodology, Funding acquisition, 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.2025.12.007.

References

Arrigoni, C., Grugnetti, A. M., & Caruso, R. (2017). Nursing students' clinical competencies: A survey on clinical education objectives. *Annali Di Igiene Medicina Preventiva e Di Comunità*, *3*, 179–188. doi:10.7416/ai.2017.2145.

Arun, R., Suresh, V., Veni Madhavan, C. E., & Narasimha Murthy, M. N. (2010). On finding the natural number of topics with latent dirichlet allocation: some observations. In M. J. Zaki, J. X. Yu, B. Ravindran, & V. Pudi (Eds.), *Advances in Knowledge Discovery and Data Mining: 6118. Advances in Knowledge Discovery and Data MiningAdvances in Knowledge Discovery and Data Mining* (pp. 391–402). Springer Berlin Heidelberg. doi:10.1007/978-3-642-13657-3_43.

Baysan, A., Çonoğlu, G., Özkütük, N., & Orgun, F. (2023). Come and see through my eyes: A systematic review of 360-degree video technology in nursing education. *Nurse Education Today*, *128*, 105886. doi:10.1016/j.nedt.2023.105886.

Belbasis, L., Bellou, V., & Ioannidis, J. P. A. (2022). Conducting umbrella reviews. *BMJ Medicine*, *1*(1). doi:10.1136/bmjmed-2021-000071.

Boboc, M., & Koç, S. (Eds.). (2019). *Student-Centered Virtual Learning Environments in Higher Education*. IGI Global. doi:10.4018/978-1-5225-5769-2.

Bozzetti, M., Guberti, M., Lo Cascio, A., Privitera, D., Genna, C., Rodelli, S., Turchini, L., Amatucci, V., Giordano, L. N., Mora, V., Napolitano, D., & Caruso, R. (2025). Uncovering the professional landscape of clinical research nursing: A scoping review with data mining approach. *Nursing Reports*, *15*(8), 266. doi:10.3390/nursrep15080266.

Butt, A. L., Kardong-Edgren, S., & Ellertson, A. (2018). Using game-based virtual reality with haptics for skill acquisition. *Clinical Simulation in Nursing*, *16*, 25–32. doi:10.1016/j.ecns.2017.09.010.

Cant, R., Cooper, S., & Ryan, C. (2022). Using virtual simulation to teach evidence-based practice in nursing curricula: A rapid review. *Worldviews on Evidence-Based Nursing*, *19*(5), 415–422. doi:10.1111/wvn.12572.

Cao, J., Xia, T., Li, J., Zhang, Y., & Tang, S. (2009). A density-based method for adaptive LDA model selection. *Neurocomputing*, *72*(7–9), 1775–1781. doi:10.1016/j.neucom.2008.06.011.

Caruso, R., Magon, A., Dellafiore, F., Griffini, S., Milani, L., Stievano, A., & Orchard, C. A. (2018). Italian version of the assessment of interprofessional team collaboration scale II (I-AITCS II): A multiphase study of validity and reliability amongst healthcare providers. *Medicina Del Lavoro*, *109*(4), 316–324. doi:10.23749/mdl.v109i4.7101.

Caruso, R., Terzoni, S., Lusignani, M., Varano, E., Pittella, F., Xharra, V., Carrodano, S., Ghizzardi, G., Conte, G., Magon, A., De Maria, M., Rocco, G., & Stievano, A. (2025). Integrating cultural competence in nursing: A scoping review of Purnell's model in clinical practice and education with data mining analytics. *Journal of Transcultural Nursing*, *36*(5), 546–559. doi:10.1177/10436596251323273.

Chen, F.-Q., Leng, Y.-F., Ge, J.-F., Wang, D.-W., Li, C., Chen, B., & Sun, Z.-L. (2020). Effectiveness of virtual reality in nursing education: meta-analysis. *Journal of Medical Internet Research*, *22*(9), e18290. doi:10.2196/18290.

Cho, M.-K., & Kim, M. Y. (2024). The effect of virtual reality simulation on nursing students' communication skills: A systematic review and meta-analysis. *Frontiers in Psychiatry*, *15*. doi:10.3389/fpsyt.2024.1351123.

Deveaud, R., SanJuan, E., & Bellot, P. (2014). Accurate and effective latent concept modeling for ad hoc information retrieval. *Document Numérique*, *17*(1), 61–84. doi:10.3166/dn.17.1.61-84.

Erlinger, L. R., Bartlett, A., & Perez, A. (2019). High-fidelity mannequin simulation versus virtual simulation for recognition of critical events by student registered nurse anesthetists. *AANA Journal*, *87*(2), 105–109.

Fealy, S., Jones, D., Hutton, A., Graham, K., McNeill, L., Sweet, L., & Hazelton, M. (2019). The integration of immersive virtual reality in tertiary nursing and midwifery education: A scoping review. *Nurse Education Today*, *79*, 14–19. doi:10.1016/j.nedt.2019.05.002.

Foronda, C. L., Fernandez-Burgos, M., Nadeau, C., Kelley, C. N., & Henry, M. N. (2020). Virtual Simulation in Nursing Education: A systematic review spanning 1996 to 2018. *Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare*, *15*(1), 46–54. doi:10.1097/sih.0000000000000411.

Griffiths, T. L., & Steyvers, M. (2004). Finding scientific topics. *Proceedings of the National Academy of Sciences*, *101*(suppl_1), 5228–5235. doi:10.1073/pnas.0307752101.

Hou, M., Lu, Y., Liu, Y., Luo, W., Xue, H., Yuan, H., & Zhang, X. (2025). The impact of virtual reality applied in nurse education on students' clinical thinking: A systematic review. *Nurse Education Today*, *146*, 106553. doi:10.1016/j.nedt.2024.106553.

Huai, P., Li, Y., Wang, X., Zhang, L., Liu, N., & Yang, H. (2024). The effectiveness of virtual reality technology in student nurse education: A systematic review and meta-analysis. *Nurse Education Today*, *138*, 106189. doi:10.1016/j.nedt.2024.106189.

Huang, X., Wang, R., Chen, J., Gao, C., Wang, B., Dong, Y., Lu, L., & Feng, Y. (2022). Kirkpatrick's evaluation of the effect of a nursing innovation team training for clinical nurses. *Journal of Nursing Management*, *30*(7), 2165–2175. doi:10.1111/jonm.13504.

Hung, H.-Y., Wang, Y.-W., Hsieh, M.-C., Chen, P.-Y., & Chang, Y.-J. (2024). Development and evaluation of a virtual reality program for immediate newborn care training in

nursing education: A feasibility study. *Perspectives on Medical Education*, *13*(1). doi:10.5334/pme.1538.
Jans, C., Bogossian, F., Andersen, P., & Levett-Jones, T. (2023). Examining the impact of virtual reality on clinical decision making – An integrative review. *Nurse Education Today*, *125*, 105767. doi:10.1016/j.nedt.2023.105767.
JBI. (2020). Chapter 11: scoping reviews. *JBI Manual for Evidence Synthesis*. JBI. doi:10.46658/JBIMES-20-12.
Jeong, S., & Cha, C. (2024). Effects of immersive virtual reality simulation–based maternity nursing education: A randomized controlled trial. *Clinical Simulation in Nursing*, *97*, 101631. doi:10.1016/j.ecns.2024.101631.
Johnson, J., Hansen, S., Hopper, L., Watson, J., Cashman, S., De Souza, W., & Mills, B. (2024). Immersive virtual reality aggression and violence management education for nursing students: A pre-test, post-test, follow-up evaluation. *Clinical Simulation in Nursing*, *97*, 101644. doi:10.1016/j.ecns.2024.101644.
Jones, K. D., Hayes, R., & McCauley, L. (2023). Strategies to evaluate and enhance accelerated second-degree nursing pathways. *Nurse Educator*, *48*(2), 59–64. doi:10.1097/NNE.0000000000001344.
Jung, E.-Y., Park, D. K., Lee, Y. H., Jo, H. S., Lim, Y. S., & Park, R. W. (2012). Evaluation of practical exercises using an intravenous simulator incorporating virtual reality and haptics device technologies. *Nurse Education Today*, *32*(4), 458–463. doi:10.1016/j.nedt.2011.05.012.
Kilmon, C. A., Brown, L., Ghosh, S., & Mikitiuk, A. (2010). Immersive virtual reality simulations in nursing education. *Nursing Education Perspectives*, *31*(5), 314–317.
Kim, Y., & Park, H. (2024). Effects of virtual reality training on clinical skill performance in nursing students: A systematic review, meta-analysis and meta-regression. *International Journal of Nursing Practice*, *30*(6). doi:10.1111/ijn.13284.
Kirvalidze, M., Abbadi, A., Dahlberg, L., Sacco, L. B., Calderón-Larrañaga, A., & Morin, L. (2023). Estimating pairwise overlap in umbrella reviews: considerations for using the corrected covered area (CCA) index methodology. *Research Synthesis Methods*, *14*(5), 764–767. doi:10.1002/jrsm.1658.
Li, X., Wei, R., Slatyer, S., & Rappa, N. A. (2025). Extended reality for enhancing communication skills in nursing education: A scoping review. *Teaching and Learning in Nursing*, *20*(2), e587–e595. doi:10.1016/j.teln.2025.01.012.
Lin, P.-C., Wung, S.-F., Lin, P.-C., Lin, Y.-C., Lin, C.-Y., & Huang, H.-L. (2024). Virtual reality-based simulation learning on geriatric oral health care for nursing students: A pilot study. *BMC Oral Health*, *24*(1). doi:10.1186/s12903-024-04249-y.
Lo, H. H. M., Fong, P. Y. H., Wang, B., Fung, C. L.-C., Wong, S. Y.-S., & Sit, R. W. S. (2025). Clinical efficacy of virtual reality cave automatic virtual environments (CAVE) for chronic musculoskeletal pain in older adults: A randomized controlled trial. *Journal of the American Medical Directors Association*, *26*,(1) 105344. doi:10.1016/j.jamda.2024.105344.
Ma, J., Wang, Y., Joshi, S., Wang, H., Young, C., Pervez, A., Qu, Y., & Washburn, S. (2024). Using immersive virtual reality technology to enhance nursing education: A comparative pilot study to understand efficacy and effectiveness. *Applied Ergonomics*, *115*, 104159. doi:10.1016/j.apergo.2023.104159.
Moyer, J. E. (2023). Virtual reality simulation applications in pre-licensure psychiatric nursing curricula: an integrative review. *Issues in Mental Health Nursing*, *44*(10), 984–1001. doi:10.1080/01612840.2023.2243330.
Obeid, M. F., Ewais, A., & Asia, M. R. (2025). NursingXR: advancing nursing education through virtual reality-based training. *Applied Sciences*, *15*(6), 2949. doi:10.3390/app15062949.
Park, S., Shin, H. J., Kwak, H., & Lee, H. J. (2024). Effects of immersive technology–Based education for undergraduate nursing students: systematic review and meta-analysis using the grading of recommendations, assessment, development, and evaluation (GRADE) approach. *Journal of Medical Internet Research*, *26*, e57566. doi:10.2196/57566.
Peters, M. D. J., Marnie, C., Tricco, A. C., Pollock, D., Munn, Z., Alexander, L., McInerney, P., Godfrey, C. M., & Khalil, H. (2021). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Implementation*, *19*(1), 3–10. doi:10.1097/xeb.0000000000000277.
Plotzky, C., Lindwedel, U., Sorber, M., Loessl, B., König, P., Kunze, C., Kugler, C., & Meng, M. (2021). Virtual reality simulations in nurse education: A systematic mapping review. *Nurse Education Today*, *101*, 104868. doi:10.1016/j.nedt.2021.104868.
Ronchi, S., Caruso, R., Fabrizi, D., Luciani, M., Alfes, C. M., Colley, N., Magon, A., Conte, G., Valli, A., Terzoni, S., Cilluffo, S., Lusignani, M., & Ausili, D. (2025). Virtual reality in undergraduate and postgraduate nursing education: A scoping review protocol integrating data mining for topic discovery. *MethodsX*, *14*, 103391. doi:10.1016/j.mex.2025.103391.
Russo, D. (2025). Pandemic pedagogy: evaluating remote education strategies during COVID-19. *Journal of Systems and Software*, *226*, 112392. doi:10.1016/j.jss.2025.112392.
Samson, J., Gilbey, M., Taylor, N., & Kneafsey, R. (2025). Virtual simulated Placements in Health care education: scoping review. *JMIR Medical Education*, *11*, e58794. doi:10.2196/58794.
Shorey, S., & Ng, E. D. (2021). The use of virtual reality simulation among nursing students and registered nurses: A systematic review. *Nurse Education Today*, *98*, 104662. doi:10.1016/j.nedt.2020.104662.
Smith, S. J., Farra, S. L., Ulrich, D. L., Hodgson, E., Nicely, S., & Mickle, A. (2018). Effectiveness of two varying levels of virtual reality simulation. *Nursing Education Perspectives*, *39*(6), E10–E15. doi:10.1097/01.nep.0000000000000369.
Sievert, C., & Shirley, K. (2014). LDAvis: A method for visualizing and interpreting topics. *Proceedings of the Workshop on Interactive Language Learning, Visualization, and Interfaces*, 63–70. doi:10.3115/v1/W14-3110.
Smith, S. J., Farra, S., Ulrich, D. L., Hodgson, E., Nicely, S., & Matcham, W. (2016). Learning and retention using virtual reality in a decontamination simulation. *Nursing Education Perspectives*, *37*(4), 210–214. doi:10.1097/01.nep.0000000000000035.
Spada, F., Caruso, R., De Maria, M., Karma, E., Oseku, A., Pata, X., Prendi, E., Rocco, G., Notarnicola, I., & Stievano, A. (2022). Italian translation and validation of the readiness for interprofessional learning scale (RIPLS) in an undergraduate healthcare student context. *Healthcare (Switzerland)*, *10*(9). doi:10.3390/healthcare10091698.
Spada, F., Caruso, R., Notarnicola, I., Belloni, S., De Maria, M., Magon, A., Conte, G., Prendi, E., Pata, X., Duka, B., Rocco, G., & Stievano, A. (2025). Analyzing readiness for interprofessional education among health program students using hierarchical clustering. *Journal of Interprofessional Care*. doi:10.1080/13561820.2025.2452973.
Spada, F., Caruso, R., Notarnicola, I., de Maria, M., Duka, B., Arapi, A., Prendi, E., Rocco, G., & Stievano, A. (2023). Describing the readiness for interprofessional education among university students attending healthcare programs: insights from a monocentric cross-sectional study. *Acta Biomedica*, *94*(5). doi:10.23750/abm.v94i5.14206.
Tene, T., Vique López, D. F., Valverde Aguirre, P. E., Orna Puente, L. M., & Vacacela Gomez, C. (2024). Virtual reality and augmented reality in medical education: an umbrella review. *Frontiers in Digital Health*, *6*, 1365345. doi:10.3389/fdgth.2024.1365345.
Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., & Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Annals of Internal Medicine*, *169*(7), 467–473. doi:10.7326/M18-0850.
Tudor Car, L., Poon, S., Kyaw, B. M., Cook, D. A., Ward, V., Atun, R., Majeed, A., Johnston, J., Van Der Kleij, R. M. J. J., Molokhia, M., V Wangenheim, F., Lupton, M., Chavannes, N., Ajuebor, O., Prober, C. G., & Car, J. (2022). Digital Education for Health professionals: an evidence map, conceptual framework, and research agenda. *Journal of Medical Internet Research*, *24*(3), e31977. doi:10.2196/31977.
Vangone, I., Arrigoni, C., Magon, A., Conte, G., Russo, S., Belloni, S., Stievano, A., Alfes, C. M., & Caruso, R. (2024a). The efficacy of high-fidelity simulation on knowledge and performance in undergraduate nursing students: an umbrella review of systematic reviews and meta-analysis. *Nurse Education Today*, *139*. doi:10.1016/j.nedt.2024.106231.
Vangone, I., Caruso, R., Magon, A., Giamblanco, C., Conte, G., Baroni, I., Russo, S., Belloni, S., & Arrigoni, C. (2024b). High-fidelity simulation and its impact on non-technical skills development among healthcare professionals: A systematic review and meta-analysis. *Acta Biomedica*, *95*(2). doi:10.23750/abm.v95i2.15601.
Vidal, V. L., Ohaeri, B. M., John, P., & Helen, D. (2013). Virtual reality and the traditional method for phlebotomy training among College of Nursing students in Kuwait: implications for nursing education and practice. *Journal of Infusion Nursing*, *36*(5), 349–355. doi:10.1097/nan.0b013e318243172f.
Vogelsang, L., Wright, S., Risling, T., De Padua, A., Leidl, D., Wilson, J., & Thompson, D. (2024). Exploring the use of immersive virtual reality in nursing education: A scoping review. *Clinical Simulation in Nursing*, *97*, 101648. doi:10.1016/j.ecns.2024.101648.
Williams, D., Stephen, L.-A., & Causton, P. (2020). Teaching interprofessional competencies using virtual simulation: A descriptive exploratory research study. *Nurse Education Today*, *93*, 104535. doi:10.1016/j.nedt.2020.104535.
Xharra, V., Caruso, R., Magon, A., Carrodano, S., Conte, G., & Stievano, A. (2024). Barriers perceived by university faculty in implementing interprofessional education: A scoping review protocol. *MethodsX*, *13*. doi:10.1016/j.mex.2024.103035.
Yang, Y., & Ma, M. (Eds.). (2013). *Proceedings of the 2nd International Conference on Green Communications and Networks 2012 (GCN 2012): Volume 1*. Springer Berlin Heidelberg. https://link.springer.com/10.1007/978-3-642-35419-9.
Zhao, J., Lu, Y., Zhou, F., Mao, R., & Fei, F. (2022). Systematic bibliometric analysis of research hotspots and trends on the application of virtual reality in nursing. *Frontiers in Public Health*, *10*, 906715. doi:10.3389/fpubh.2022.906715.

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