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TOPICAL REVIEW

Digital Transformation in Nursing Education: A Systematic Review on Computer-Aided Nursing Education Pedagogies, Recent Advancements and Outlook on the Post-COVID-19 Era

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ABSTRACT The COVID-19 pandemic has transformed nursing education worldwide. Due to the globally applied restrictions of interpersonal interactions, many educational institutions transitioned from traditional to computer-aided nursing education pedagogies. However, an obligatory change, this digital transformation in nursing education, has been deemed promising by students and academics, yet raising concerns about the effectiveness of innovative nursing pedagogies. Hence, this systematic literature review aims to investigate the state of the art of computer-aided nursing pedagogies in the post-COVID-19 era and provide recommendations for further research investigation. Specifically, it utilises a mixed methods approach to examine (1) the evolution of computer-aided nursing pedagogies before and after COVID-19; (2) their effectiveness against traditional methods in terms of knowledge, skills acquisition and self-efficiency; and (3) nursing students' experiences and opinions when exposed to computer-aided nursing education pedagogies. For this purpose, several databases (PubMed, MEDLINE, CINAHL Complete, Academic Search Elite, IEEE, ACM, Scopus, ERIC and Cochrane Library (Controlled trial requests) were searched, initially retrieving 802 articles published between 2013-2023. After removing duplicates, exclusion criteria and assessment for eligibility, the number of articles assessed for eligibility was reduced to 78 conducted in 20 different countries. The articles comprised quantitative research (n=37), including Randomised Control Trials (n=14) and Quasi-experimental studies (n=23), and qualitative research (n=41) including observational studies (n=14), mixed-methods methodological design (n=15), pilot studies (n=7) and conference papers (n=5). Moreover, this SLR utilised the Joanna Briggs Institute (JBI) methodological approach for conducting a mixed-methods systematic review (MMSR) and provided a narrative synthesis of all studies. The results of this mixed-methods SLR suggested that the post-COVID-19 era has enabled the implementation of a variety of computerised systems in nursing education, including desktop-based systems, mobile applications, Virtual Reality, Augmented Reality, Mixed Reality and holograms, haptics, Artificial Intelligence-enabled chatbots and systems, smart glasses and multimodal systems. The authors found that these computer-aided nursing education pedagogies were superior to traditional nursing pedagogies regarding acquiring knowledge, skills, and self-efficiency. However, the generalisability of the above findings should be interpreted with caution due to variations in sample size and effect size established via Hedges' g calculations among the 35 quantitative articles. Nevertheless, nursing students' experiences and opinions were encouragingly positive. Further research is needed to incorporate more realistic and memorable scenarios and examine the effects of computer-aided nursing educational pedagogies on long-term knowledge gains and the effective learning domain.

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INDEX TERMS Nursing, education, computer aided systems, student satisfaction, knowledge gains, COVID-19, digital transformation.

I. INTRODUCTION

Recent technological advances and the COVID-19 pandemic has disrupted healthcare education worldwide [1], which prompted healthcare educators to incorporate online collaborative learning environments [2]. Nurses have a broader scope of practice and responsibilities than other healthcare professionals, as they apply scientific methods and practices and therapeutic interventions, human communication, connection, empathy, intuition and imagination [3]. Therefore, online pedagogies are convenient for theoretical knowledge delivery; however, practical skills are challenging to be exercised online. A worrying finding in 2019 reported that the attrition rate of nursing undergraduate students in the United Kingdom (UK) is 24% [4]. According to [5], the second most common reason for student nurses' dropout is insufficient resources and techniques to achieve their learning outcomes effectively. As a result, the question of how traditional nursing pedagogies will be replaced with technology without compromising education is raised by nursing educators [6]. Emerging technologies such as Virtual Reality (VR), Augmented Reality (AR), and computer-based simulation with haptic techniques are among the latest advances suggested for use in nursing education [2]. One of the recent goals of "The International Nursing Association for Clinical Simulation and Learning (INACSL)" for nursing education is to implement VR, AR, Mixed Reality (MR) and serious games in nursing education. However, their effects on nursing students' learning, patient outcomes, communication and decision-making are still being investigated [7].

Furthermore, most nursing educational methods and practices are outdated, and educators and policymakers must consider the COVID-19 pandemic as an opportunity to identify new pedagogical requirements [2], [8], [9], [10]. The 'Future of Nursing 2020-2030 report' highlights nine recommendations to transform nursing education in the modern world. One of which is to 'Assess access to virtual learning and multisector simulation for all students including those in geographically and socioeconomically disadvantaged settings', with recommendations to educators and tutors to pay specific attention to students from diverse backgrounds, implement the simulation and virtual pedagogies to enhance learning [3]. More evidence is needed regarding the effectiveness of alternative technology in nursing education, including research studies examining qualitative and quantitative findings [6], [11]. The authors stressed the need for researching simulation in nursing education and focused on investigating computerised nursing pedagogies' outcomes with heterogenous samples, larger samples, mixed methods and Randomised Control Trials (RCTs) [11]. Moreover, researchers must be willing to investigate and document evidence and best innovative educational practices comprehensively [12]. This systematic literature review (SLR) examines the current state of the art regarding computer-aided nursing pedagogies, addressing three research questions (RQs) illustrated in Table 1.

Figure 1 provides the organisation and systematic framework of the review and is explained as follows. Section II describes the paper's contributions. Section III presents some case studies already applied in nursing educational institutions. Section IV describes the methodology, and Section V illustrates the literature analysis. The results are presented in Section VI, followed by the discussion in Section VII. Limitations and future recommendations are provided in Section VIII. Finally, this SLR draws a conclusion in Section IX.

II. CONTRIBUTIONS

To the best of the authors' knowledge, this is the first recent study which applied a mixed method approach (i.e. combining quantitative and qualitative data) to investigate the state of the art of computer-aided nursing education pedagogies before and after the COVID-19 era. Other SLRs were conducted in a similar research domain, such as [13], which examined computer-based nursing education only in undergraduate nursing students. However, this study might not reflect recent developments, as it was conducted between 2007 and 2010, including 9 studies only. Furthermore, the article addressed e-learning environments (i.e. web-based learning, personal digital assistants, and instructional videos), excluding concepts such as gamification and simulation. In addition, investigating nursing students' experiences (i.e. qualitative research) was not included in this study's objectives. Similarly, the authors in [14] conducted an SLR with meta-analysis, including 17 experimental studies, to examine the effectiveness of technology-based nursing education pedagogies. However, the authors only addressed undergraduate nursing students and did not include qualitative data collection in their studies [14]. Moreover, a state-of-the-art literature review of technology in nursing and midwifery education was conducted between 2016 and 2020 by [15]. The authors included articles on simulation, VR, videos and other methods (e.g. comparing high-fidelity to low-fidelity animal models), focusing only on the psychomotor domain (i.e. the skills nursing students learn during practice). The topic could have been further explored if the cognitive (i.e. theoretical knowledge) and affective (values, emotions, breaking bad news, etc.) domains were also included. Finally, a state-of-the-art literature review provides a general overview of a topic of interest and does not include quality appraisals or provide a specific answer based on pre-defined RQs [16]. Hence, the effectiveness of technology-based nursing education pedagogies against traditional methods and nursing students' experiences were not examined.

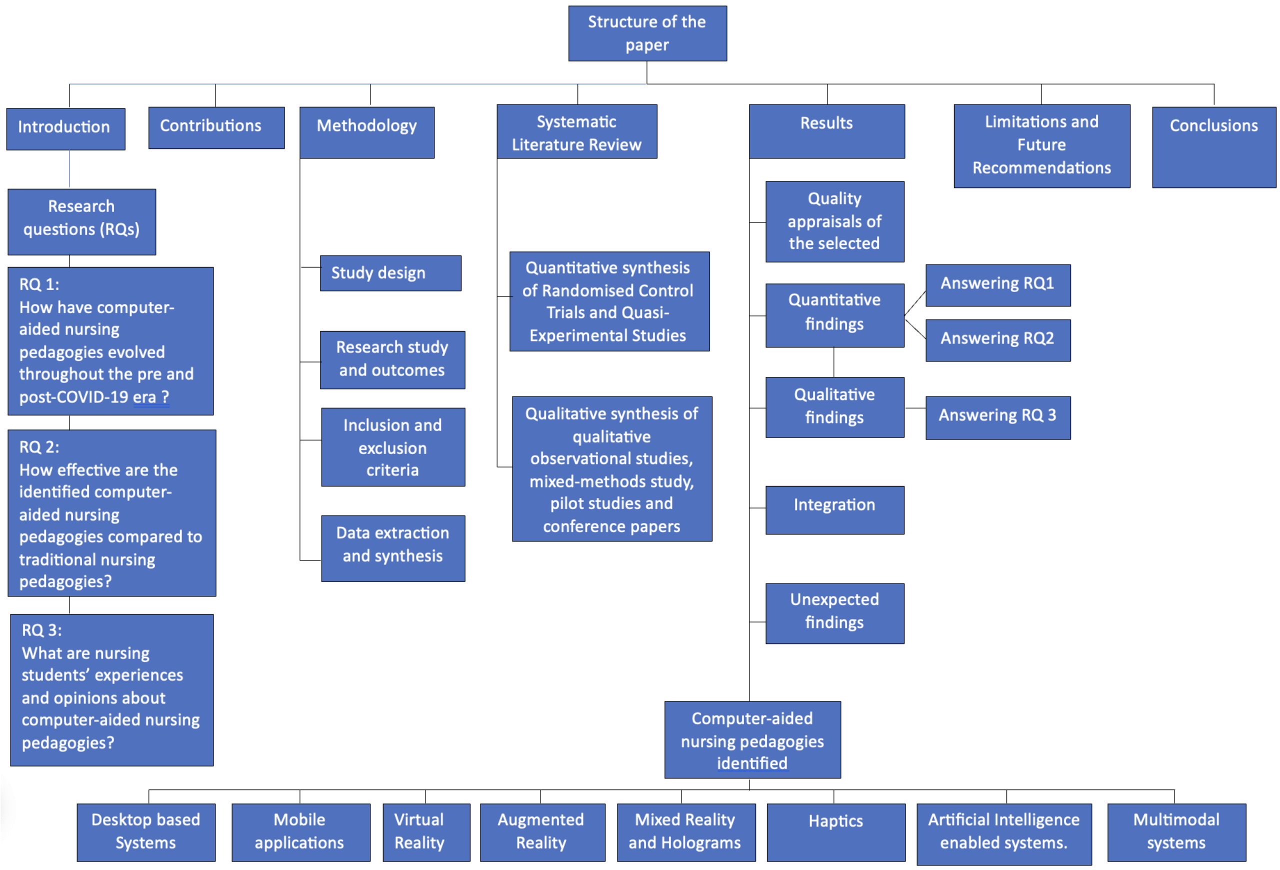

FIGURE 1. Illustration of the RQs, topics, and technologies covered in the paper.

TABLE 1. Research questions.

Question No.	Question
RQ1	How have computer-aided nursing pedagogies evolved throughout the pre and post-COVID-19 era ?
RQ2	How effective are the identified computer-aided nursing pedagogies compared to traditional nursing pedagogies?
RQ3	What are nursing students' experiences and opinions about computer-aided nursing pedagogies?

Other researchers focused on nursing undergraduates and only mobile technology by reviewing fourteen quasi-experimental studies and RCTs [17]. At the same time, [18] and [19] only focused on examining Artificial Intelligence (AI) -based technology in nursing education. An SLR examining VR-based technology in nursing education was conducted by [20]. However, the authors only focused on VR technology and did not include qualitative findings such as nursing students' opinions and experiences with VR-based nursing education pedagogies. Likewise, [21] examined the effectiveness of VR technology in nursing education, focusing only on knowledge gains as an outcome of interest and including only RCTs. Education technology in medical training during the COVID-19 pandemic has been investigated by [22]. However, the authors conducted a survey paper review, including only haptic technology, VR and AI regarding surgical training of medical students. Consequently, the authors did not examine the effectiveness of the haptic, VR and AI technology against traditional methods and did not obtain medical students' opinions and experiences through qualitative research.

This SLR differs from the studies mentioned above in several aspects. The essential contributions of this study can be summarised as follows:

1) We reviewed 78 primary articles on computer-aided nursing pedagogies from 20 countries, published between 2013-2023. Thus, our SLR would provide an in-depth comparison of computer-aided nursing pedagogies before and after the COVID-19 pandemic.
2) We reviewed a variety of computer-aided nursing education pedagogies, such as VR, AR and MR concepts incorporated into mobile phones and desktop systems, haptics, holograms, AI-enabled Chatbots, smart glasses and multimodal systems in nursing education.
3) Our mixed-methods design allowed articles with diverse study designs to be thoroughly examined. In contrast to the related work above, qualitative data considering nursing students' experiences and opinions on computer-aided nursing pedagogies were also explored in this SLR.

4) The quantitative data obtained via RCTs and quasi-experimental studies examined the effectiveness of computer-aided pedagogies against traditional nursing education methods. Therefore, providing an in-depth understanding of computer-aided effectiveness and student nurses' experiences.
5) The study population of the articles included in this SLR focuses on all qualification levels, i.e. from undergraduate to graduate to nursing practitioners, each with different knowledge levels and experience. This could be seen as a more extensive review of the current state of the art in computerised education pedagogies in nursing, compared to only examining undergraduate nursing students.
6) Finally, this SLR critically appraised all studies included, highlighting a potential improvement in the methodological approach for nursing educators and researchers.

These are valuable contributions to knowledge, as other researchers might compare how nursing education has evolved before and after the COVID-19 pandemic.

III. CASE STUDIES

Computer-aided nursing pedagogies have already been applied in some educational institutions. This section presents a brief overview of selected case studies taken from universities' official websites.

For instance, the Hong Kong Polytechnic University (PolyU) nursing faculty developed and implemented a computer-aided haptic system for educating nursing students about Nasogastric tube (NGT) insertion. The haptic device has been used successfully at the university after the pilot testing performed in 2016 by [23]. Likewise, "Stanbridge University" in the United States of America (USA) introduced the Haptic Intravenous (IV) Trainer developed by "Ledral Medical", which offers a real-world practice of IV line insertion by utilising a realistic touch sensation via feedback technology. This interactive training opportunity was dedicated and applied to nursing students at the Nursing School at Stanbridge University [24]. The University of New England (USA) provided the opportunity for nursing students to access innovative teaching methods via their smartphones during the COVID-19 pandemic [25]. Bournemouth University in England implemented software with a VR headset for nursing education, developed by the technology company "Daden" and academic and healthcare professionals from Bournemouth University. The student nurses could access the software on their mobile phones and computer desktops. It has been successfully used for nursing students' education about hypoglycaemia (low blood sugar) in the wards at Royal Bournemouth Hospital [26]. Similarly, the University of Tusla (USA) implemented a 3-Dimensional (3D) VR simulation for a Bachelor's degree in nursing [27]. Brooklyn College in the USA adopted the Virtual Immersive Reality training program for nursing students, developed by the company "Unitek Learning" in 2021 citeUnitek. The company "UbiSm" [28] founded in 2016, offers a variety of Immersive VR services for educating nursing students based on individual demands. Currently, some universities benefiting from UbiSm are "Texas Tech University Health Sciences Center", "Suny Corning Community College", " California State University Northridge", "Central California Community College", "Illinois State University", "University of West Florida", "National University", "Unitek Learning" [28]. A similar concept was adopted by the company "SimX" [29] utilises VR, AR and simulation for healthcare education, including nursing students. SimX was the first company to develop the first comprehensive software for VR simulation regarding medical simulation, applicable to nursing students, in 2013. The educational institutions utilised SimX include "Standford University", "The Penn University of Pennsylvania", "The University of Nebraska/College of Nursing", "The University of Texas in Austin", "The International University of Health and Welfare", "The Ohio State University", " Indiana University" [30].

IV. METHODOLOGY

Conducting an SLR requires thoroughly examining the available literature and identifying all the available work related to a topic of interest [31], [32], [33], [34]. The methodology of conducting this SLR can be divided into five stages, as shown in Figure 2. The methodology is further explained in the sections below.

A. STUDY DESIGN

This paper adopts a mixed-methods approach to answer its RQs presented in Table 1. The mixed-methods study design was chosen for more comprehensive evidence of (1) computer-aided nursing education pedagogies' effectiveness against traditional nursing education methods and (2) student nurses' experiences and opinions when exposed to computer-aided nursing education pedagogies [35].

To answer RQ1, the publication date and pedagogy type of all 78 studies included in this SLR are considered. The quantitative data (addressing RQ2) is extracted from RCTs or Quasi-experimental studies. According to [36], RCTs are the most suitable study design to address the effectiveness of an intervention. Although quasi-experimental studies are more prone to bias due to the lack of randomisation, they can still be used if very few RCTs are published on a subject [36]. The outcomes of interest for the quantitative studies are computer-aided nursing education pedagogies effectiveness against traditional lecture materials (e.g. notes, videos, low fidelity mannequins). Specifically, the effectiveness will be measured by knowledge and skills acquisition, clinical reasoning, academic performance, and self-efficiency.

On the other hand, the qualitative data (addressing RQ3) is gathered from qualitative or mixed-methods primary research articles, conference papers and pilot studies. The phenomena

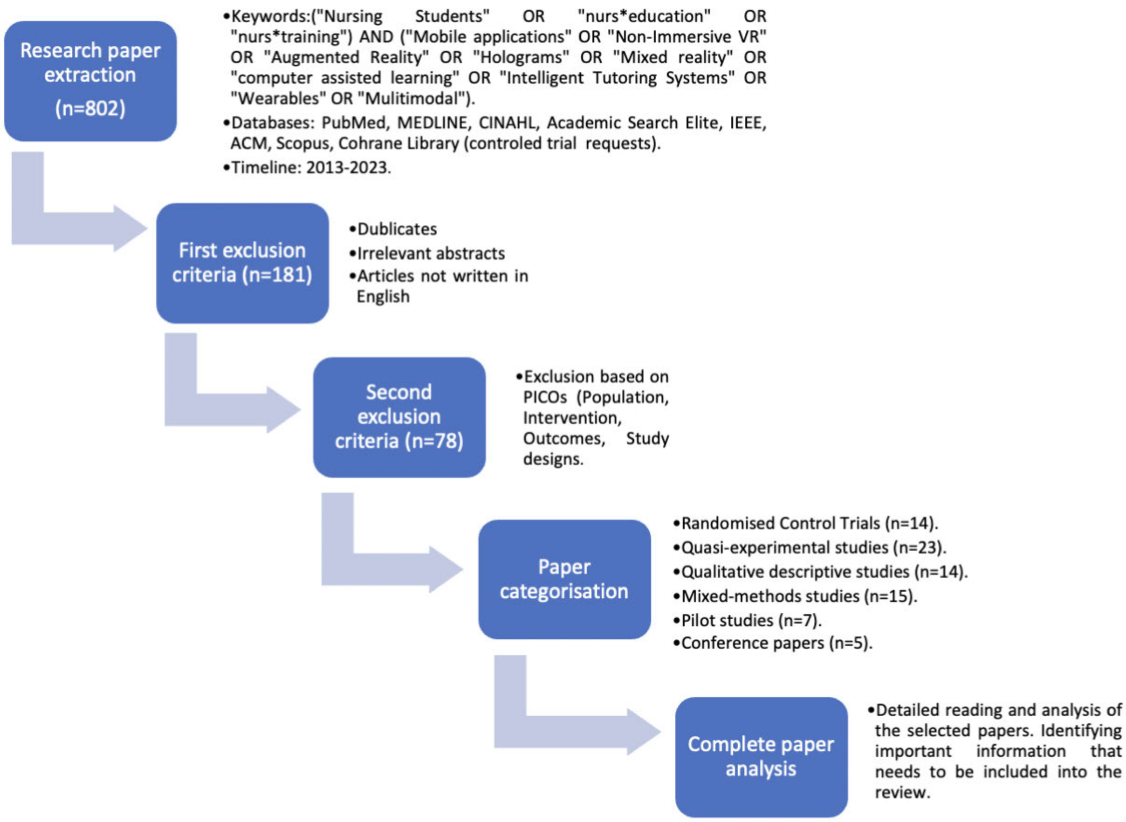

FIGURE 2. Methodology adopted in the SLR.

of interest for the qualitative studies are nursing students' experiences, feelings and opinions about computer-aided nursing pedagogies [35].

B. SEARCH STRATEGY AND OUTCOMES

Several databases were explored between March 2023 and October 2023 for articles published between 2013-2023. The selected databases are PubMed, MEDLINE, CINAHL Complete, Academic Search Elite, IEEE, ACM, Scopus, ERIC and Cochrane Library (Controlled trial requests). Moreover, the used keywords were: "("Nursing Students" OR "nurs* education" OR "nurs* training") AND ("Mobile applications" OR "Non-Immersive VR" OR "Augmented Reality "OR "Haptics" OR "Holograms" OR "Mixed reality" OR "computer assisted learning" OR "Intelligent Tutoring Systems" OR "Wearables" OR " Multimodal")". Initially, 802 articles were identified and screened for duplicates and relevance. After removing duplicates and exclusion criteria, the number of articles assessed for eligibility was reduced to 181. Following the second assessment for eligibility, the total number of articles included in this SLR was 78 articles conducted in 20 different countries. The articles included 14 RCTs, 23 quasi-experimental studies, qualitative observational studies (n=14), mixed-methods studies (n=15), pilot studies (n=7) and conference papers (n=5). This process is explained in Figure 2.

C. INCLUSION AND EXCLUSION CRITERIA

The PICOs (Population, Intervention, Comparison, Outcome, Study type) framework [37] was chosen to inform the inclusion/exclusion criteria for the articles in this SLR, given in Table 2. Abstracts and articles not peer-reviewed were not included in the 78 retrieved articles. Only articles including nursing students exposed to computer-aided nursing education pedagogies, examining either the system's effectiveness or nursing students' experiences, were selected.

D. DATA EXTRACTION AND SYNTHESIS

A Microsoft Excel template was used for the data extraction of all 78 articles in this SLR. The extracted data includes authors, year, country, database, study type, type and purpose of computer-aided pedagogy in nursing education, number of participants, interventions (exposures) and outcomes.

In regards to the data synthesis and integration, the updated version of the Joanna Briggs Institute (JBI) methodological approach conducting a mixed-methods systematic review (MMSR) was utilised [35]. According to JBI, a convergent approach (i.e. the data synthesis occurs simultaneously) is most appropriate for conducting mixed methods SLR.

Furthermore, the two types of convergent approaches, convergent integrated or convergent segregated, could be selected as a framework based on the study's RQs. The former is applicable if either quantitative or qualitative data could

TABLE 2. The search tool, inclusion and exclusion criteria.

PICOS	Inclusion Criteria	Exclusion Criteria
	Studies in English from 2013-2023.	Articles not in English; Articles not free of charge.
Population	Articles on nursing education focused on the involvement of only nursing students or partly nursing students.	Articles addressing only nurses or healthcare professionals.
Intervention	Studies addressing computerised tutoring systems include using computers, tablets, and mobile phones.	Articles considering immersive VR, online learning platforms, and blended learning.
Comparison	Studies including an experimental group exposed to computer-aided pedagogical methods, compared to a control group exposed to traditional nursing educational methods such as lecture notes, classroom videos, etc.	Studies comparing two alternative traditional nursing educational methods to each other, studies without a control group (assessing effectiveness).
Outcomes	Studies examining outcomes of interest, such as knowledge and skill acquisition, confidence, nursing students' experiences, opinions, etc.	Studies examining other outcomes (development, technical aspects, etc.)
Study design	Randomised Control Trials (RCT) and Quasi-Experimental Studies. Qualitative and mixed methods studies, grey literature examining nursing students' opinions and experiences.	Articles concerning other theoretical nursing pedagogies.

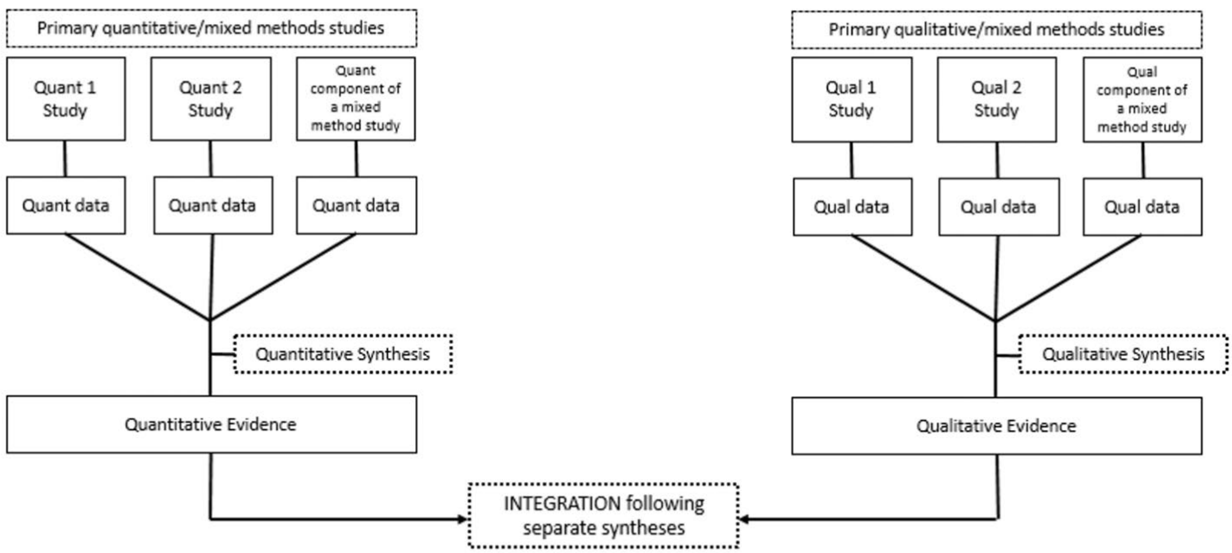

FIGURE 3. A convergent segregated approach based on JBI guidance [35].

answer the RQs and allows the combination of both data types simultaneously. On the other hand, if a study requires both qualitative and quantitative data to answer its RQs, a segregated convergent approach should be implemented [35]. This SLR adopted the segregated convergent approach as it examines both the effectiveness of computer-aided nursing education pedagogies (i.e. quantitative data) and student nurses' experiences and opinions (i.e. qualitative data). The segregated convergent approach will present the data synthesis and results separately and then integrated into a join synthesis [35], as illustrated in Figure 3.

The meta-analysis did not apply to this SLR, as the RQs and mixed–methods design prompted articles with diverse interventions, outcomes of interest and study designs. Instead, the narrative synthesis approach was implemented as recommended by the authors in [35]. Furthermore, based on the RQs, the quantitative data is presented first, followed by the qualitative data.

E. QUALITY APPRAISAL OF THE SELECTED STUDIES

A quality appraisal is a thoroughly and systematically carried out process of assessing the trustworthiness of a study by examining its methodological quality [38]. A quality appraisal is usually presented as a checklist and is performed in an SLR for three reasons, as mentioned by the authors in [39] and [40]. First, to exclude studies of low quality, which may negatively impact the validity of this SLR recommendations. Second, to highlight the strengths and weaknesses of the included studies and determine if the findings are representative of the study population of interest. Third, to conclude if study weaknesses have affected the end results [40]. This SLR chooses three Critical Appraisal Tools (CATs) to assess the methodological quality of the studies. The quantitative studies, RCTs and quasi-experimental studies were evaluated using the Cochrane risk of bias tool for RCTs (RoB 2) [41] and JBI appraisal tool for quasi-experimental studies [42]. The quality assessment for the qualitative studies was performed based on the Clinical Appraisal Skills Programme (CASP). The RoB 2 tool autogenerates scoring systems and automatically presents the results of quality appraisals. In contrast, CASP and JBI checklists were manually completed. All three quality assessments were completed by the authors.

V. LITERATURE ANALYSIS

This section is divided into two parts. It begins with the quantitative synthesis, only including the RCTs and quasi-experimental studies. Then, the qualitative synthesis is presented, which includes articles examining nursing students' experiences and opinions regarding computer-aided nursing education pedagogies.

A. QUANTITATIVE SYNTHESIS

In the following sections, within the quantitative synthesis, the RCTs and quasi-experimental studies are not presented in a specific order but rather organised based on the nursing education pedagogy type. In this section, participants exposed to a computer-assisted nursing pedagogy method are referred to as the "experimental group", and participants exposed to traditional nursing educational methods (lectures, video materials and low-fidelity mannequins) are mentioned as the "control group".

1) DESKTOP-BASED SYSTEMS

Anatomage Table (AT) technology was created to replace human cadavers for proper learning about human anatomy and physiology [43]. It is a 3D virtual human cadaver where students can see an artificial human body under the screen and manipulate organs via interactive images retrieved from computed tomography (CT) scans, X-rays, etc [43] A quasi-experimental study conducted by [43] examined nursing students knowledge gains and experiences. A total of 503 nursing students were exposed to learning anatomy via AT (experimental group), and 132 nursing students were exposed to traditional lectures (control group). The results showed an average positive experience using the AT (84%), and 91.2% reported a realistic representation of human anatomy. The knowledge gains in the experimental group were significantly higher (p<0.05) than in the control group. However, in terms of effectiveness compared to online teaching, only 51.3% favoured the AT, and 46.6% still preferred a real human cadaver. However, students needed more time to familiarise themselves with AT, and only students from one semester at the university were recruited. In addition, nursing students in the group using the AT were almost three times as many as the group exposed to traditional lectures [43].

Computer-Assisted Instructions (CAI) is the narrowed term under the broader concept of Computerised Assisted Teaching (CAT) and allows the computer to act as the teacher by providing and directing instructions [44]. A quasi-experimental study was conducted to examine the effects of a CAI on nursing students' satisfaction, knowledge acquisition and self-efficacy regarding a scenario about nursing care of a diabetic pregnant woman was performed [44]. The authors divided 80 participants equally into two groups: the experimental group (n=40) used the CAI, and the control group (n=40) was exposed to traditional lectures. Compared to traditional face-to-face methods, 82.50% of CAI participants reported higher knowledge levels and self-efficacy. Still, their satisfaction could have been better due to issues with old equipment or low internet speed in some cases [44].

A desktop-based virtual RAPIDS (Rescuing a Patient in Deteriorating Situations) simulation was created with "Flash" software for teaching purposes in nursing education in regards to managing deteriorating patient [45]. A total of 5 different scenarios related to managing and communicating a deteriorating patient were implemented into the system. Once entering the virtual ward as a virtual nurse, the nursing student chooses the scenario based on the admission day of the patient and the steps of managing the case based on the pre-defined options via control menus. This action eventually unfolds other possible steps, depending on the pre-selected options. An RCT was conducted, where 31 nursing students practised e-RAPIDS (experimental group) and 26 nursing students practised on a low-fidelity mannequin (control group). The authors were interested in examining the effectiveness of the RAPIDS in terms of knowledge gains and student performance. The results were obtained immediately after the experiment and after 2.5 months, concluding a similar increase in knowledge in both the first and second post-tests. However, the second post-test of the experimental group was significantly lower (p<0.05) than the first post-test. In contrast, there was no difference in the two tests in the control group (p=0.94). In addition, both groups had similar knowledge gains and performance results. However, the outcomes were measured by a self-assessment tool, which could lead to biased self-reported results [45].

A game-based desktop system was suggested for nursing students' education about electrocardiogram (ECG) reading interpretation [46]. The system incorporated clinical context into the game developed with "RPG Maker MV", which enabled nursing students to access the system via desktop computer, identify issues with ECG results, and therefore make decisions based on the readings, scenes and storylines to enhance their learning process. The game interacts with the students by storing their learning data and presenting learning materials accordingly. The authors conducted a quasi-experimental study to test the game's effectiveness in terms of learning performance, critical thinking, motivation and attitudes. A total of 72 nursing students were divided into experimental groups (exposed to the desktop-based system) and control groups (exposed to traditional lectures). The results were in favour of the experimental group in all pre-defined outcomes. Regarding learning performance, the experimental group performed significantly better ($F=22.08$, $p<0.001$) than the control group. In addition, learning motivation($F=400.65$, $p<0.001$) and learning tendency ($F=647.58$, $p<0.001$) were higher in the experimental group. Furthermore, the critical thinking component was more noticeable in the experimental group, as the game options challenged the nursing students to implement critical thinking to progress in the next stage of the desktop-system game. Despite the overall agreed effectiveness of the game, the authors expressed some concerns about whether the nursing students' "excitement" of utilising the game has affected the results. Therefore, they have recommended further investigation of long-term gains and the excitement factor in utilising innovative approaches in nursing education [46].

A 3D desktop-based game was designed with the development platform "Unity", consisting of a scenario about nursing surgical care knowledge of a hospital ward, accommodating a virtual patient [47]. Expressions and real equipment graphics were incorporated to improve the reality perception of nursing students. To assess the nursing students' surgical knowledge, the authors divided nursing students into an experimental group (n=140) and a control group (n=136). Both groups were assessed based on 6 subareas of surgical procedures in nursing (blood transfusion, haemorrhage, perioperative assessment for orthopaedic surgery and peripheral artery surgery, pain management). The results of this quasi-experimental study concluded that both groups showed variations in their knowledge in different subgroups. However, overall knowledge gains in the experimental group were significantly higher ($p<0.001$) than the results in the control group. Nevertheless, for the full integration of this desktop-based system into the nursing curriculum, the authors of this study recommended incorporating practical exercises (i.e., inserting a urinary catheter) to enhance psychomotor skills in nursing students [47].

Serious 3D games and their effectiveness against traditional nursing lectures have been investigated by [48]. The authors randomly assigned 194 nursing students, where the experimental group (n=28) used a computer-aided software system, i.e. "3D MedSim BLS". In contrast, the control group (n=28) were educated via self-learning and in-class training. The computer–based game focused on Cardiopulmonary Resuscitation (CPR) training, dedicated to nursing students and was designed based on the American Heart Association (AHA) and European Association Council (ERC). This quasi-experimental study found no differences between the two groups regarding the time of CPR implementation and scores. However, the group that used the game performed better and was more confident. In nursing, "learning by doing" is essential, and it is suggested by the authors that, specifically in life-threatening scenarios, having the chance to practice procedures can be beneficial for patients [48].

A neonatal resuscitation serious game simulation (NR-SGS) software was designed based on a scenario of a 39-week-old baby with a compromised respiratory function [49]. The game-based software uses written, visual, and audio stimuli. The 2020 neonatal resuscitation (NR) algorithm regulates the steps in this game-based scenario, such as if a baby needs resuscitation, the starting and terminating criteria, the steps to be taken, etc. The authors tested the efficiency of this game against the traditional methods on 90 nursing students by performing a quasi-experimental study. The participants were equally divided into experimental and control groups, where formal theoretical learning with videos about practical skills was delivered to both groups. Then, the experimental group was exposed to the NR SGS five times (each on a different day), where knowledge and skill level assessments were integrated into the application. The results showed that the lecture-based training had positively affected theoretical knowledge; there were no differences between the two groups. However, regarding ventilation and compression skills, the experimental group was statistically better ($p = 0.11$) than the control group ($p = 0.20$). No difference was found in self-confidence and student satisfaction in both groups, as both were high. However, the high cost of the software is classified as a limitation, along with the fact that some students with no personal computers were excluded from the study. The authors recommended a longitudinal study to examine the long-term effects and test the systems with other scenarios [49].

2) MOBILE APPLICATIONS

A mobile application facilitating an educational intervention program was designed to educate nursing students about chest tube care and monitoring [50]. The "iLearning" application was developed by the software developer program "Notion" and consisted of 5 components, including information about the chest tube and chest tube care, preparation and patient education, concept mapping scenarios, chest tube quiz and online discussion. Thus, nursing students gained a theoretical background in chest tube insertion and care, followed by video-based scenarios. Nursing students' knowledge was assessed via quizzes, with the top 5 performers receiving an artificial price for their high scores. Finally, a collaborative discussion was available. A quasi-experimental study divided 53 nursing students into an experimental group and 54 nursing students into a control group, assessing the effectiveness of the iLearning application in terms of clinical reasoning and self-efficiency. The results indicated significantly higher self-efficiency and clinical reasoning abilities in the experimental group ($p<0.05$) compared to the control group. These results persisted for a week and a month after the experiment, suggesting long-term knowledge gains in nursing students who used the iLearning application could be achieved. However, some technical issues negatively affected the learning experiences due to low Cloud server speed [50].

A mobile application for educating nursing students about infusion pump manipulation was suggested by [51]. This interactive application consists of several stages where nursing students can complete learning objectives about infusion pump manipulations by receiving positive or negative feedback. The effectiveness of the mobile application in terms of level of engagement and learning acquisition was measured against traditional lectures about infusion pump' utilisation. Therefore, 94 nursing students were allocated to an experimental group utilising the application, and 87 nursing students were assigned to a control group which received traditional lectures. The results showed no significant differences between the two groups in terms of learning acquisition, level of engagement and learner confidence. In addition, there was no difference between the two groups in terms of the time needed to operate the infusion pump. However, the participants in this RCT had different levels of exposure to the smart application of infusion pump monitoring before the experiment, which might have influenced the findings [51].

The mobile application "Study@Campus" was proposed as an alternative method for nursing students to communicate with their tutors about their learning objectives [52]. The application consisted of a network-group communication platform and information about sessions, learning plans, etc. An RCT examined the self-efficiency and competence outcomes by dividing nursing students into two groups. The experimental group (n=52) used the "Study@Campus" application, and the control group (n=50) communicated as usual with their educators(via emails, face-to-face, etc.) for five weeks. The results concluded no significant difference between both groups regarding competence and self-efficiency (p=0.37). However, some technical difficulties (inconsistency in presenting session schedules) experienced by participants in the experimental group might have led to frustration in some nursing students [52]. A mobile application was proposed as an effective method for medication dose calculating in nursing students [53]. A detailed description of the mobile application was not provided, but its effectiveness was tested against manual calculation among 100 nursing students. The skills acquisition and execution time were measured equally and divided into two groups: experimental (using the application) and control (using a calculator). The results of this RCT concluded the experimental group's superiority in terms of time needed to complete the calculation/dosing (15.7 minutes) and the skills acquisition (mean score = 8.14) compared to the control group (38.9 minutes and 5.02 mean score). However, immediate feedback and the possibility of collaborative learning features were requested by nursing students in future application development [53].

A mobile application was designed to enhance the theoretical and practical knowledge of nursing students [54], but a detailed description of the mobile application was not provided. The mobile application accommodated collaborative learning, as it was used as an effective communication tool between members, resulting in team-based learning (TBL) activities. The authors performed a quasi-experimental study to test the mobile application's effectiveness in problem-solving abilities and skills acquisition. Consequently, 60 nursing students were equally divided into an experimental group (utilising the mobile application and traditional routine training) and a control group (traditional training). The results concluded a significant improvement in the problem-solving techniques and clinical skills (p<0.001) in favour of the experimental group, compared to the control group. However, the fact that the experimental group had greater exposure (both traditional methods and mobile applications) might have influenced the results [54]. A mobile interactive learning and diagnosis (MILD) system utilised, consisting of learning, diagnostic and teaching systems, was proposed to enhance nursing students' learning experiences about problem-based learning in the nursing profession [55]. MILD consist of a human instructor who arranges and manages learning activities based on diagnostics generated by students' responses. The system is activated via a mobile device, and a Quick Response (QR) code initiates the learning activities. A quasi-experimental study was conducted to examine the knowledge acquisition and cognitive load of nursing students who use the system compared to nursing students exposed to traditional nursing lectures. For this purpose, 20 nursing students were assigned to an experimental group, and 16 were allocated to a control group. It was evident from the results that the MILD system has high learning gains, as the results from the experimental group were significantly higher than the control group in terms of knowledge acquisition (p=0.003<0.05, F=10.61). In addition, the cognitive load of the MILD was significantly lower in the experimental group than in the control group. However, some limitations of the MILD system were reported. For example, as the system is passive, the students often had to manipulate it manually (use a QR code to access the next activity), interrupting their learning process [55].

A mobile application called "Clinic Vitals" was used to educate nursing students on vital signs measurement [56]. A crossover, a quasi-experimental study, examined nursing students' skill and knowledge acquisition in an experimental group using the application (n=19) compared to nursing students exposed to a traditional lecture in a control group (n=22). The results concluded that there were no significant differences between the two groups. More interesting recommendations were suggested, such as gamification and application in different languages in nursing education. Although the authors did not conclude the superiority of the application against traditional methods, "Clinical Vitals" was recommended as a mode of educational delivery for places with limited teachers' availability, as 97.7% of the participants stated that the application helped them to some extent to learn about vital signs. However, the small sample size and internet connection requirement were seen as limitations. The authors recommended that future researchers focus on examining the application's effect on low-income areas where resources are limited [56].

Similarly, [57] designed and implemented an interactive mobile application called "i- STAR". The application was created from a professional nursing perspective, and the idea was based on the "Framework of Competencies in Clinical Reasoning" for nursing students [58]. Three paediatric scenarios had to be completed by following specific steps. The application was compatible with IOS and Android smartphones; however, the authors did not report a detailed technical process of the application development. As "i-STAR" appeared promising, the authors tested its efficiency by conducting a quasi-experimental study to evaluate clinical reasoning, self-efficiency and learning satisfaction. The control group (n=86) had only traditional lectures and quizzes, while the experimental group (n=77) was exposed to the "i-STAR" application. Pre-tests were done for both groups, and similar levels of knowledge were confirmed between the two groups. In post-test one and post-test two, the participants in the experimental group showed higher user satisfaction, but their academic performance was similar ($p< 0.05$). In addition, there was no correlation between academic knowledge scores and sex/age. The knowledge level examined in the post-tests was significantly higher than the control group. However, there were some technical issues when using the application, mainly due to a poor internet connection. The authors called for the personalisation of each student in terms of connection and phone features. The authors concluded that this study needs to prove the correlation between using the application and better academic performance and suggested more diverse participants and different application scenarios [57].

The social media Instagram application has been suggested as a useful concept in nursing education [59]. An RCT was conducted to test the web page Ventroglutral, specifically for teaching purposes in nursing students. The experiment group (n=69) was given access to the application, and the control group (n=69) was exposed to traditional nursing lecture teaching. The study continued for five days, where the experimental group used all the benefits of the Instagram application, such as posting comments, likes, sharing content, and uploading stories. Instagram posts were the most common way of presenting learning materials to the students and writing comments and likes was a form of feedback between students and instructors. The materials were related to intramuscular (IM) injections, where the knowledge and skills of the participants of the two groups were compared. The control group only used the class materials and presentations and no other interventions. The groups were examined on the measures quantitively, immediately after the intervention and 15 days later. The results showed that regarding knowledge and skill accusation (i.e. preparation and application of an IM injection), the Instagram application results were similar to the lecture-based control group. Also, there was no relationship between gender and skills and knowledge scores [59].

A game-based mobile application to educate nursing students about flushing venous catheters was suggested [60]. A mobile application, "cocos2D game", developed using C++ language, was compatible with Android devices. To confirm the effectiveness of the application, the authors conducted an RCT including 154 nursing students, divided into 2 groups (experimental and control) of equal participants (n=77). The nursing student participants were exposed to a face-to-face theoretical lecture, followed by a demonstration and opportunity to practice on a low-fidelity mannequin, where a single-blinded instructor observed them. Then, the control group had no more interventions, but the participants in the experimental group downloaded the application and had to use it for a week. The authors measured the skill acquisition, error incidence and average performance attempt using the application via quantitative surveys. The results showed that the skill performance scores of the experimental group were higher than the control group, and the error occurrence was lower. In addition, participants needed 11 attempts to understand the application to use it successfully and thoroughly. The application was suggested by the authors for short-term knowledge gain. However, only the experimental learning curve was examined, as no data was produced from the control group. Therefore, the control between the two groups in terms of the learning curve cannot be compared. The authors suggested a longitudinal study to examine the long-term effect of the application [60].

An application called "Guess It (SVUAL)" was suggested for educating nursing students about life support techniques (both basic and advanced) [61]. The "Guess It (SVUAL)" application was designed by various professionals, including registered nurses, computer specialists, doctors and psychologists. The participants could select a correct answer among key terms appearing on the screen, which needed to be put in order. Also, the words had to be assigned correctly to either advanced life support or essential life support. The application was partly developed based on guidance from the American Health Organization (AHA) and the European Resuscitation Centre (ERC). The authors conducted an RCT by allocating 92 participants to the experimental and 92 to the control groups. All 184 participants were nursing students exposed to traditional lectures to assess their initial knowledge, after which only the experimental group was given the application. After three weeks, the control group received an additional lesson about the topic, while the experimental group was first introduced to the application. Then, the experimental group used the application and was finally provided with a close-ended questionnaire regarding their knowledge and gameful experience. The control group also completed a questionnaire after the lectures, and three weeks later, both groups completed the questionnaires again. The results indicated that the experimental group had higher knowledge than the control group in both tests. The gamification experience (based on five items) was high; therefore, the application was recognised as a good and enjoyable experience in nursing education. However, only knowledge was measured, not practical skills. The authors recommended that future researchers include skills acquisition measurements as well. Although this application was only in Spanish, authors recommended the use of this application in other languages and with other healthcare professions [61].

3) AI-ENABLED CHATBOTS

A chatbot utilising a knowledge-based interactive system, "Anatomy Quiz", was proposed as a part of anatomy class in nursing undergraduates [62]. The authors performed a quasi-experimental study, testing the chatbot's effectiveness, explicitly focusing on academic performance, critical thinking and learning satisfaction [62]. A total of 32 nursing students from one university were equally divided into two groups; the control group received information about the topic via the traditional lecture method, while the experimental group used the application. The results concluded chatbot's effectiveness in education, as those students reported better learning satisfaction, critical thinking and academic performance. Furthermore, interactive learning enabled personalisation in education gains. It was considered user-friendly, as it could be downloaded onto a phone or a tablet. However, this study did not monitor the learning process and, therefore, did not examine issues they might have encountered, such as technical difficulties or poor application features. The authors recommended that future researchers assess how learning is affected by participants' personality traits and consider investigating teacher perspectives. In addition, cross-disciplinary research was recommended, where software developers, educational technologists, and clinicians participated in developing a chatbot. Finally, according to the authors, to enhance student satisfaction, other techniques, such as gamification, should be implemented [62].

A "Disease Management" chatbot was developed to teach nursing students about vaccine administration in pregnant women [63]. The "Disease Management" chatbot provides instant feedback on theoretical questions such as infectious diseases and pandemic news. In addition, incorporating natural language processing (NLP) into the chatbot facilitates real-like communication, which benefits nursing students. Usually, this topic is delivered through lectures, but it is challenging for nursing students to learn it due to its complexity. Many factors, such as medical history and specific vaccine details, must be considered before administrating a vaccine [63]. A quasi-experimental study by the same authors compared 18 students using the chatbot (experimental group) against 18 students exposed to traditional teaching (control group) from one university. The authors measured self-efficiency, learning experiences and academic knowledge. Overall, participants using the mobile-based chatbot reported better and in-depth learning, enhanced self-efficiency and better awareness about vaccination in pregnancy compared to the control group. Some recommendations include other AI technology, such as built-in image recognition features, for identifying easily administered vaccines. In addition, it is important to understand students' perspectives or characteristics when applying chatbot context. Moreover, a challenge in this chatbot scenario was that as vaccination development progresses, the team will have to update the algorithms and relevant information, which can be time and resource-consuming [63].

An AI-enabled chatbot was designed and tested for practising nursing students' electronic fetal monitoring (EFM) skills [64]. The authors developed the interface using LandBot.io, where algorithms, customised intervention, and NLP were implemented to customise questions and answers. A total of 61 junior nursing students from one university (n=31 in the experimental group and n=30 in the control group) took part in this quasi-experimental study. The control group was exposed to traditional video lectures, and the experimental group used the chatbot. The results showed no significant difference between the two groups regarding clinical reasoning, knowledge, feedback, satisfaction, and confidence. However, the experimental group showed more interest in learning and had improved self-efficiency. Nevertheless, the experimental group was also exposed to the video, and the questions in the chatbot were related to answers addressed in the previously watched video. In addition, this chatbot provided feedback as part of the predictive analysis (transaction chatbot) and could not answer a specific question asked by students. The authors proposed future research to examine the effects of chatbots on knowledge retention [64].

4) VIRTUAL REALITY

A Pharmacology Inter-Leaved Learning Virtual Reality (PILL-VR) simulation was proposed as a low-cost learning system for nursing students' education on medication administration [65]. The PHILL-VR, designed via the open-source 3D Desktop VR multi-platform, consists of an artificial hospital ward with lying-in-bed patients and a room with medical and nursing supplies. A nursing student enters the environment as an avatar via a desktop computer. Nursing students could manipulate the avatar and follow one of the two available scenarios related to medication administration while receiving feedback and video directions. A quasi-experimental study assessed the learning outcomes and the sense of presence in the PILL-VR environment, dividing nursing students into experimental (n=82) and control (n=47) groups. The results concluded significantly higher knowledge gains in the experimental group compared to the control group (p<0001). Moreover, the follow-up assessment five months later reported equal results between the post-test and the first post-test, confirming long-term learning gains when nursing students utilised PILL-VR.

In addition, most participants reported a high degree of presence when immersed in the VR environment. Nevertheless, the participants in the experimental group were almost double the size of the participants in the control group, which might have affected the findings in favour of the experimental group [65]. A Mobile Virtual Reality Educational Program (MVREP) for teaching nursing students aseptic techniques in a surgical environment was suggested by [66]. The MVREP consisted of VR glasses showing a 3D video. The video was related to a detailed practical guide on surgical techniques and was downloaded to participants' smartphones, connecting them to the VR glasses. In this quasi-experimental study, the authors measured the skill acquisition, including 40 nursing students (22 in the experimental and 18 in the control group). The experimental group was exposed to the MVREP, while the control group learned via video lectures. A quantitative approach was used to assess the participants, in addition to an observation performed by a blinded instructor 15 days after the initial test. As a result, the participants in the experimental group acquired better aseptic techniques ($p < 0.001$) compared to ($p=0.002$) in the control group. In the second assessment, the results were similar, with a slight difference in the two hand-washing skills in favour of the experimental group. The authors were concerned that the scenario was specific and the results might not be generalisable for the broad spectrum of scenarios used in nursing education [66].

A mobile, game-based, non-immersive VR application was suggested as an alternative to traditional educational methods in nursing education [67]. This application was created with Adobe Flash Professional CC and Adobe Flash CS6 technologies; no internet was needed. A tracheostomy-based scenario was implemented, where a virtual nurse was caring for a patient with a tracheostomy by introducing the concept and guiding the students throughout the game. A total of 86 nursing students participated in this RCT. All participants were exposed to a lecture about tracheostomy, followed by a practice on a low-fidelity mannequin. Then, participants were equally divided into experimental and control groups, and the experiment group was given the application. The control group's knowledge and skills were measured a week after the lectures but were not reported to prevent observer bias as the study was single-blinded. Quantitative questionnaires were used to measure the average score. After the results of the control group were reported, participants from the experimental group downloaded the application on their phones and were given seven days to practice. The results showed that the average score of the experiment group in terms of knowledge and skill acquisition was higher than the control group, which was a statistically significant result. However, it is unclear how often each student practised to master the skills [67].

A virtual simulation game (VSG) was introduced as an innovative practice for nursing students' education [68]. The authors were interested in assessing the VSG's effectiveness in teaching the nursing process, such as diagnosis, goal setting and prioritising prognosis. The authors compared 102 first-year nursing students, randomly assigning them to experimental and control groups. The experimental group was introduced to the user-centred 2D VGS, consisting of a simulated virtual patient accessible via a computer desktop. The system unfolds its steps based on the user's previous choices. In the event of an incorrect response, the user is presented with an explanation video, which plays the decision chosen by the user and feedback. Then, a new opportunity is raised again to repeat the choice. On the other hand, the control group used a traditional lecture. Quantitative methods were used to examine the researchers' questions, resulting in a significantly higher goal-setting and nursing diagnosis knowledge in the experiment group ($p < 0.05$) compared to the control. Regarding the understanding of prioritising prognosis, the differences were not significant ($p>0.05$). Participants also pointed out that the scenario was realistic, and the game was easy to navigate. However, some participants pointed out that the lack of familiarity with the system prevented them from participating in the game promptly. In addition, the authors also noted that the game was new and not practically tested on various cases. Nevertheless, they conducted a pilot test before it was implemented in this study, where some technical issues and video quality were corrected. The authors recommended applying the game to all phases of the nursing process and reporting findings [68].

A VR simulation program software for neonatal infection control for nursing students called "HirNIC" was introduced [69]. The system consisted of a VR set with a laptop, a hand-tracking device, a Motion Controller, and a Full Kit Head Mounted Display (HMD) with a sensor. These attributes allow the nursing student to enter the VR scenario by wearing the HMD and, therefore, act as a nurse. The controller tracks the hands' movement. The authors also performed a quasi-experimental study to examine the effectiveness of the "HirNIC" in terms of nursing knowledge, self-efficacy, and user satisfaction. They compared an experimental group ($n=26$) using "HirNIC" to a control group ($n=25$) with traditional lectures. The results concluded that the experimental group had significantly higher satisfaction and self-efficiency but were not very different in knowledge acquisition than the control group. However, the time constraints during the debriefing might have affected the results, as the three scenarios presented at the simulation only had 20 minutes for debriefing. The authors recommended the implementation of cooperative learning in future nursing simulation programs [69].

5) AUGMENTED REALITY

The AR Humanitude AR Training System (HEARTS) consisting of a Microsoft HoloLeans 2 device and a mannequine was suggested for educating nursing students on both psychomotor and affective skills when interacting with people with Dementia (PwD) [70]. Nursing students could view the facial expressions of a "patient" by wearing the AR glasses projected over the mannequin. An RCT was conducted to assess the effectiveness of HEARTS in terms of affective skills acquisition. Nursing students in the experimental group (n=21) were exposed both to HEARTS and the mannequin, and the control group (n=17) were exposed only to the mannequin. The results showed that the experimental group had a significantly better empathy score due to the ability to make eye contact with the "patient" and understand their facial expressions (p=0.039) compared to the control group (p=0.501). In addition, 95% of the participants have accepted HEARTS as an effective, innovative educational tool in nursing, as it facilitates realistic communication. However, there might be some limitations about the applicability of the proposed system due to the high cost. In addition, the projected patient face was cartoon animated, and it is unclear how nursing students would respond to a human face integrated into the system [70]. A Mobile Augmented Reality (MAR) application measuring the knowledge and skills of nursing students for administrating injections was proposed in [71]. The educational and training programs of the MAR were created with software such as UNITY 3D, 3D MAX, After Effects, Gamtasia, and Vuforio. They included interactive games, videos, and QR codes providing information and guiding the students. The authors divided 64 recruited nursing students into the experimental group (exposed to MAR) against 58 nursing students in the control group (exposed to paper-based notes). A pre-test was conducted to examine the levels of expertise between the two groups, which were statistically insignificant. The results of the control showed that the experimental group had better understanding ($p < 0.05$) and skills acquisition ($p < 0.05$) in both first and follow-up tests, compared to the control group. However, both groups showed high knowledge maintenance on the follow-up test. The authors recommended using MAR; however, there might be issues with compatibility and technical maintenance due to the application's complexity and the use of personal smartphones. The MAR used in this study was developed with the help of software specialists [71].

The AR concept was integrated into undergraduate nursing education about pressure ulcer care [72]. The authors introduced the AR experience, created by HP Reveal and Aumentary Creator, which could be downloaded onto a smartphone or a tablet. In this quasi-experimental study, 137 nursing students were divided into an experimental group (n=72) and a control group (n=65). The authors were interested in knowledge and skill acquisition as outcome and learning determinants in the experimental group. The experimental group could use their phones, and the scenario included an introduction to the topic, diagnostic test, dressing and compression therapy. The control group relied on lecture notes or videos, while the experimental group benefited from AR technology. The results revealed that the AR group had significantly better knowledge and skills outcomes ($p<0.001$). In addition, the learning determinants were (1) attention and motivation, (2) autonomous learning, and (3) comprehension. However, the authors found that new technology will typically attract more attention. The pre-test participants' knowledge was measured, and there was no difference. Students reported that it gives them more realistic interpretations of the wound care they might encounter later in practice. Some limitations, such as a homogenous sample size, affected the generalisability of the studies [72].

An AR-enabled mobile application for teaching undergraduate nursing students about the anatomy and physiology of the heart was proposed in [73]. An AR camera feed utilised an animated model of a heart, which could navigate via Apple's "ARKit2" platform. The participants could move their phones according to the desired angle, resulting in real-time changes. Also, educational material was available on the screen due to the incorporated user interaction (UI) model. In real-time, students could change settings affecting the 'working' of the heart, such as blood pressure, heart rate, etc. The authors tested the AR application by performing a quasi-experimental study, assigning 19 junior nurses to the experimental group and 14 to the control group. The control group used traditional video lectures. When examining the post-test, there were no differences between both groups, with 38.9% stating why the AR application would be preferred over traditional lessons. However, most (88.2%) said they would happily use a similar AR-enabled application for knowledge gain. The open questions result indicated that students would prefer incorporating more exciting features, such as sound, visual effects, and interactive components, which could support the suggestion above. Additional issues with the artefact were that the reliability and validity were compromised due to the question's consistency issues, which might have affected the results. The authors suggested that different universities could participate in further research and more significant samples, including other healthcare specialities [73].

A system incorporating AR technology into a medical simulator (Resusci Anne model), enabling different emergency scenarios, was presented in [74]. The AR-based paediatric first aid training and evaluation system (AR-PFAES) uses an AR software development kit (Vuforia) to detect and monitor real-time images, where a camera is used instead of a QR code to scan and augment an image. The authors tested the technology on 46 nursing students against 49 fourth-year nursing students. Both groups completed pre-test questionnaires before using the AR-PFAES (experimental group) and the Resusci Ann low-fidelity mannequin (control group). The results showed that the experimental group showed statistically significant knowledge gain ($p < 0.05$) compared to the control group, as well as skills ($p<0.001$) and self-confidence ($p<0.001$). However, no cost was mentioned, and an AR expert was called to help the research team design the AR application. Therefore, the maintenance of the proposed pedagogy may not be cost-effective for general use in nursing education, particularly in developing countries. Nevertheless, the authors mentioned that low-fidelity mannequins could only work with one scenario and more figures are needed to fulfil different scenarios. Consequently, purchasing more low-fidelity mannequins could be more expensive than an AR application in the long term [74].

6) MIXED REALITY AND HOLOGRAMS

The use of 3D holograms in nursing education has been highlighted by [75], who proposed a tool consisting of a VR software system (i.e. Patient First Patient Condition and Health Assessment) and hardware (i.e. VR Remote control and Windows MR Helmet). The authors examined the effects of the hologram system on knowledge and skill acquisition by recruiting 79 nursing students. Following a pre-test, participants were randomly assigned to experimental and control groups of 40 and 39 nursing students, respectively. The experimental group received education via the 3D hologram, and the control group only traditional lectures. The experimental group had statistically significant ($p<0.05$) knowledge and skill gains as opposed to the control group. Additionally, the experimental group reported high student satisfaction and enthusiastic views about hologram use in nursing education. However, some functionalities still needed to be fully developed in this 3D hologram, such as game attributes, self-assessment, hints, etc. Moreover, some concerns about the time and expenses of implementing this hologram in nursing education emerged. The authors recommended the involvement of subject matter professionals to develop future hologram technology and be able to design based on specific nursing module learning goals [75].

7) HAPTICS

An intravenous (IV) injection insertion education system for nursing students was introduced by [76]. The system, called Virtual Intravenous Simulation (VIS), consists of a computer interface, software program, haptic device, and VR component. Physical contact between the computer interface and the nursing students occurs via the haptic device. 60 nursing students were included in this quasi-experimental study, divided into two groups. All students were exposed to a traditional method of plastic arm and demonstrated the IV injection procedure. Then, the experimental group (n=30) were given the VIS and the control group (n=30) video lectures. There was no significant increase in knowledge between the experimental and control groups for the post-test results compared to the pre-test. Also, the self-confidence between the two groups was similar. Considering that the pre-test scores of the two groups were statistically significant, the authors acknowledged the non-randomisation of the participants as a substantial limitation. Also, it needed to be clarified how much time the control group spent watching the video and whether this impacted the results; a proper scale measuring self-confidence needed to be included, too [76].

The effectiveness of a virtual-simulation-based mobile application with haptic technology in nursing education was explored by [77]. The scenarios included in the application addressed nasotracheal care in patients and were addressed to educating nursing students. The authors tested the effectiveness of the application against traditional teaching methods; hence, they divided 100 students equally into an experimental group and a control group. This RCT tested participants' knowledge, skill acquisition, learning satisfaction and cognitive load. The quantitative assessment showed that the experimental group had better knowledge, skill acquisition, and learner satisfaction scores than the control group. In addition, the experimental group had a lower cognitive load. However, some limitations exist, such as that all participants were females. Also, it could be suggested that the demographics were incomplete, while the university which accommodated this RCT was described as 'polyethnic'. Initially, the authors implemented the measure tools for knowledge and skills development, and their validity has not been widely confirmed. Also, the long-term effects of knowledge retention were not examined. The authors specifically focused on recommendations about accessing longevity, as they pointed out that an application design is often time-and cost-consuming [77].

An RCT to examine the urinary catheterisation skills of 96 nursing students was conducted by [78]. Initially, all participants were given a traditional lecture on urinary catheterisation. Then, the experimental group (n=39) was exposed to a 3D System Touch Haptic Simulator, a computer-based haptic arm equipped with real-time feedback. The control group (n=40) had no other interventions. The results concluded that the experimental group showed higher levels of satisfaction and catheterisation skills than the control group. However, some sociodemographic characteristics varied regarding student satisfaction in the experimental group. The authors recommended enhancing the experience of haptic technology in nursing, for instance, by including a haptic interactive glove or a VR environment [78].

8) MULTIMODAL SYSTEMS

An innovative technology called "VIVEPAPER" (developed by High Tech Computer Corporation (HCT) Corporation) in nursing education was suggested [79]. Essentially, this technology is a virtual book which 'provides immersive reading experience', combining VR and AR concepts, immersive reality video, pictures and audio. By wearing an HMD, the user can easily activate the VR and AR components of the system, 360 photos, etc., by simply touching a paper book in front of them. The authors aimed to test the system's efficiency in helping nursing students develop nasogastric tube feeding practices by measuring their post-test knowledge, practical skills, confidence and satisfaction. An RCT was performed by allocating 45 nursing students into an experimental group (n=22) and a control group (n=23). The experiment group used the "VIVEPAPER" with an implemented scenario, and the control group was exposed to a DVD video containing relevant teaching material. The results showed that the two groups' skills, knowledge and confidence were similar. Student satisfaction was the only attribute when the experimental group reported significantly higher results than the control group. In addition, one month after the intervention, the results for knowledge and confidence were still equally high for both groups compared to their baseline scores at the beginning of the project. The authors reported that time for familiarising the device should be allowed when assessing technology-based outcomes in nursing education. Similarly, other aspects should be considered, such as the headset weight, technical issues with some parts of the devices, etc. In addition, 23% of the participants reported feeling nauseous, and the authors concluded that more attention should be paid to assessing and addressing cybersickness in potential nursing student users [79]. A VR simulator with a haptic device was proposed as an effective educational tool for nursing students' nasogastric tube (NGT) insertion [80]. This concept involves a physical NGT, a human head model, and a graphic user interface (GUI) with a built-in haptic device (designed with fuzzy logic and finite element method). Thus, nursing students can insert an NGT, feel the resistance, or observe the GUI for realistic feedback, such as cough. In addition, the system can verbally respond, giving instructions such as when the "patient" should swallow. A quasi-experimental study divided nursing students into an experimental group, utilising the system (n=40) and a control group practising on a low-fidelity mannequin (n=39). The outcomes of interest were knowledge gains and acceptance level, with the acceptance rate of the VR simulator being proved "high". The results concluded no significant differences between both groups, as both groups' knowledge about NGT tube insertion had equally increased. However, some demographics (age and NGT previous practice) were significantly different between the two groups, which might have influenced the end results [80].

B. QUALITATIVE SYNTHESIS

This section includes nursing students' opinions and experiences about computer-aided nursing pedagogies obtained from qualitative observational studies and the qualitative components of mixed-methods studies, plot studies and conference papers. Similarly to the quantitative synthesis, this section organises the articles based on the type of pedagogy.

1) DESKTOP-BASED SYSTEMS

A desktop-based serious game in nursing education about assessing premature newborn babies, called "E-Baby", was proposed by [81]. The game concept consists of a baby placed in an incubator, where the student nurse could view the baby's history, interact with the baby, select options, and answer questions about the baby's oxygenation based on their judgement. In addition, a nurse student can record their interaction via an option presented on the interface. Nursing students had the opportunity to interact with E-Baby for 15 days and provide their feedback. The system was generally accepted as very useful in nursing education, with the interactive component being highly favourable to nursing students. Likewise, the autonomy, ease and flexibility of the game-based desktop system were highly praised by nursing students. However, students' experiences and opinions were examined via a close-ended questionnaire. In addition, a few nursing students reported that they could not access the game due to technical difficulties. [81].

A desktop-based simulation based on a pre-defined scenario about pain management was introduced to nursing students as an innovative nursing pedagogy method [82]. Nursing students could interact with the system via computer screen, where a scenario of a male or a female patient admitted to a hospital unfolds based on the previously chosen options by the nursing students. Nursing students participated in the study to evaluate the desktop-based simulation via open-ended questions. One of the nursing students' recommendations was to increase the system's realism by adding more features to the "patients", such as the ability to read their body language for pain detection. All participants agreed that this type of education pedagogy will benefit their curriculum, as it is a modern and interactive way compared to the "boring slides" of a traditional lecture. Nevertheless, some nursing students pointed out that the inability to ask questions and get immediate feedback from the system is the major downfall of this desktop-based simulation [82].

A computer-based text messaging system for nurse practitioners' education was proposed in [83]. The online simulation was designed based on a scenario and included text-based communication between a care provider and caretaker/patient. A total of 17 nurse practitioner students collected critical information from the conversation and, based on that, decided on a diagnosis and plan of action. The results from this study showed that the participants felt significantly more knowledgeable and confident about recognising patients' signs and symptoms. The authors suggested a larger sample size to examine the effectiveness of computer-based simulations in the future [83].

A computer-simulation-based interactive educational program, "ComEd", was developed by [84]. The system was based on an integrated pre-recorded scenario and utilised video production equipment. Furthermore, the incorporation of video-based algorithms was mentioned, but the authors did not specify the algorithms' type. In "ComEd", the students played the role of nurses, and the patient was an interactive virtual patient. The authors examined the accessibility, practicality and feasibility of the system by interviewing nursing students. Most students were optimistic when using "ComEd". However, the system is yet to be declared functional, as it was only tested on a small number of participants from one institution. In addition, as the authors reported, the instrument they used to measure outcomes needed to be better studied. Nevertheless, the authors have recommended that the next stage involve more realistic scenarios and discover practices that support non-verbal communication, such as VR, special equipment, etc. [84]. In addition, the cost of such a program and the preparedness of educational institutions to implement it must be investigated [84].

A serious game web application called ''Virtual ER'' was designed to enhance interprofessional communication in healthcare education, specifically in the Emergency Room Department (ER) [85]. The application has an interactive component (i.e. Tumult Hype) being evaluated by both nursing and medical students, resulting in improved teamwork practices and generally positive attitudes. However, the nursing students' perspectives were not prioritised as most participants were medical students, and the authors focused more on examining different personality traits rather than the differences between experiences in nursing and medical students. Nevertheless, the system was declared useful in enhancing interprofessional communication. For more accurate results, the authors recommended that future studies include a control group for comparison [85].

A digital escape room for nursing education was developed via the Genial.ly platform [86]. By logging into Moodle and Google Meet, the participants could log in to the computer and be allocated to different meeting rooms by a facilitator. A user solves various puzzles and follows hints to escape the room. The authors tested this computer-based educational game by examining the gameful learning experiences and learning outcomes perceptions of 136 nursing students from one university. Participants reported high motivation while playing the game and optimised collaborative learning experiences; however, learning outcomes were not measured [86].

A serious computer-based 3D game for educating nurses about cardiopulmonary bypass was suggested in [87]. ''Virtual Perfusionist'' is a storytelling video game based on a heart surgery scenario. The game has been developed by the Hospital Clinic de Barcelona and the University of Barcelona and was among the three projects to win an award for innovation, knowledge delivery and social impact in healthcare by the La Caixa Foundation Technology Center in 2021. The game itself directs the roles of the surgeon, the patient and the anesthesiologist, and the user controls the nurse. The user can perform nursing tasks during the surgery, where a scoring scale of 100 points is implemented, and the user loses points for every incorrect procedure in this virtual operation theatre. The authors measured students' experiences with the game, resulting in reports of general motivating and satisfying experiences. However, the authors reported that the game's development was not time and cost-effective [87].

A virtual tele-simulation was designed for the collaborative learning of healthcare professionals, among which were 214 nursing students [88]. The tele-simulation was intended via the Unity 5 game engine and used the Zoom platform. The system consisted of a computer that allowed the participants to virtually navigate inside the simulation environment and communicate with each other or the patient avatar via headphones, earphones and a microphone. Medical and nursing students were expected to act based on a scenario and plan and deliver treatment for a patient with sepsis. Their perspectives on using the system in terms of learning and practice skills were examined via four focus groups. The application added a new appreciation of each other's role in healthcare, leading to better interprofessional relationships. However, some participants felt that realism was missing from this simulation, as they could not physically see the patient [88].

2) MOBILE APPLICATIONS

The authors in [89] designed the ''BeeDa'' application to aid in learning theoretical materials for undergraduate nursing students. ''BeeDa'' application architecture involves a Learning Management System (LMS) and Content Management System (CMS), which provides 24-hour content available via the Internet. Only students and lecturers could access the material as CMS was incorporated into the design, which promoted data protection. The usability was evaluated via the Usability Acceptance Test (UAT). Although students' opinions were positive, the application was only compatible with Android mobile devices, potentially impacting its general usability among nursing students [89].

Instagram, a popular social media platform, was utilised to measure nursing students' satisfaction and perception of learning gains [90]. The competition consisted of goals and tips for nutrition for keeping astronauts healthy in the international space station. Every day, the selected nursing students were expected to answer two multiple-choice questions, which provided the students with immediate feedback. The responses were then reported (via Instagram shares) either daily or weekly, depending on the task on a daily report. The majority of the participants concluded that the quiz helped them understand the concept and would recommend it to other students. However, these were close-ended questionnaires, which did not allow the authors to explore students' experiences thoroughly [90]. Despite the overall positive experiences, the authors pointed out that implementing similar applications to nursing education is not without risk, as the application could be discontinued from use by their creators or become costly to maintain [90].

The educational game i.e. ''Kahoot!'' was used to enrich and evaluate the subject of ''Management and Administration of Nursing, Ethics and Health Legislation Services'' in nursing educational classes [91]. One of the good features was the ranking scheme, monitoring the response rate, which promotes competitive experiences. However, as the authors reported, it is difficult to conclude a correlation between ''Kahoot!'' and good academic performance, as the authors did not monitor other confounding factors such as previous knowledge, study time, etc. Therefore, the authors concluded that "Kahoot!" would be an excellent tool for promoting competitiveness and participation in nursing students, resulting in positive student satisfaction and student-teacher communication. However, a study design with a control group was recommended for more comprehensive study findings [91].

3) AI-ENABLED CHATBOTS

An AI-enabled chatbot was incorporated into an existing online library services application to enhance nursing students' experiences with online requests [92]. The "BCNPYLIB CHATBOT" was created, which enables constant and interactive, 24-hour communication with the nursing student. However, when evaluated, nursing students did not report major differences in user experiences or learning satisfaction before and after using "BCNPYLIB CHATBOT". Acknowledging the insignificant differences, the authors planned to enhance this AI application by incorporating NLP for more interactive communication and library administrators' workflow relief [92].

Similarly, the authors in [93] have investigated nursing opinions on using a chatbot facilitating clinical decision-making called "SafeBot" in a simulated emergency situation. "SafeBot" is a healthcare application that can be downloaded on desktops and mobile phones. Once logged in, the users were prompted to different scenarios based on their job location (primary vs secondary care) to assess a patient experiencing pesticide poisoning. Participants found it feasible, and the acceptance rate was generally high. On the other hand, some participants pointed out that they could reject innovative technologies because of fears that they will increase their workload. In addition, fear of unknown technology was suggested as another reason for the low acceptance of a conversational agent in a real-life healthcare environment. Nevertheless, nursing students were highly satisfied with "SafeBot" as it promotes patient safety. Participants in this study reported that incorporating voice recognition could further enhance the usefulness of this chatbot [93].

A virtual counselling application using AI for nursing undergraduates was suggested by [94]. The Google Cloud's Dialog flow was used to train the chatbot via the NLP technique, which was later integrated with the Unity 3D engine to produce the 3D avatar. The application was based on four case scenarios and was directed to communication skills enhancement in nursing students. It was piloted, and enthusiastic opinions emerged, such as improving nursing students' confidence and experiences. However, it was found that the lack of real-life conversations was found to be a limitation of this project [94]. The "E-MunDiabetes" application, downloadable to either a smartphone or a tablet, was developed for clinicians for educational purposes of people with diabetes during the COVID-19 pandemic [95]. The application, compatible with iOS and Android devices, was created based on diabetic management guidelines and consisted of 5 screens based on different scenarios and quizzes. Once downloaded, E-MunDiabetes can also be accessible offline. The application was evaluated by nursing students, who reported high satisfaction and positive opinions. However, the instrument used to measure nursing students' perspectives was a close-ended questionnaire. In addition, a few participants reported technical difficulties downloading the application [95]. A mobile device was suggested as a low-cost alternative for a near-infrared (NIR) device for venipuncture for nursing students' education [96]. The device was named "mVeinVision" and incorporated a standard camera Universal Serial Bus(USB) connected to a smartphone, light source (NIR) light-emitting diodes (LEDs)) and an image processing algorithm. The mobile application was compatible only with Android devices, and the cost was estimated between $30-80. Nursing students were asked to evaluate the feasibility of the mobile device by examining the ability to identify veins in 25 patients. Nursing students concluded general positive attitudes towards the device and high acceptance level, although, at this stage of development, this is simply a high-fidelity prototype. In addition, the experiments were performed during the daytime, in a controlled lighting condition, which might question the feasibility of the mobile application device in different environmental factors [96].

4) VIRTUAL REALITY

A desktop non-immersive 3D application using VR in nursing education was proposed in [97]. The application was created so students could learn about nursing communication practices without supervision and receive instant feedback. After an observational study, most participants were more motivated to learn with positive attitudes. In addition, realism (as participants could see an actual patient) was the primary positive outcome. However, technical issues arose (e.g. poor Wi-Fi connectivity), and some students needed clarification on the instructions. This led to frustration and confusion in some participants. In addition, immersion sickness (i.e. a feeling of dizziness when using the HMD) was reported by several nursing students. The authors recommended testing the system against traditional teaching methods to examine its effectiveness in learning outcomes [97].

A VR game addressing the prevention of needle stick injuries in medical and nursing students was developed in [98]. The engine "Unity 3D" was used to create the game, which allowed visuals, text and animation to be presented on the computer screen. The VR-based computer system consisted of 10 safe or unsafe scenarios and steps related to needle usage, allowing the user to follow one or the other. Then, the game displays immediate feedback with either correct or incorrect decisions and task completion time. When tested on nursing students and medical students, the VR-based game showed improved knowledge and performance about needle stick injury prevention while at the same time decreasing their anxiety about the occurrence of such an event. However, the self-reported questionnaire used in this study might have introduced a reporting bias [98].

5) AUGMENTED REALITY

An AR application was developed for learning purposes of nursing students about lung functions in the "Anatomy and Physiology" module [99]. The application was installed on an iPad and is activated by targeting markers in the form of printed logos on both sides of a T-shirt. An illusion of a real lung visualisation was created, as nursing students could view lung physiology on a person wearing the T-shirt. Nursing students' experiences were investigated, creating conventional findings. Some nursing students appreciated the realistic lung images and were optimistic about utilising the application in their anatomy learning modules. On the other hand, other nursing students preferred the app to be just a supplement to their textbooks, as it did not provide theoretical information about the respiratory system. In addition, some technical issues were reported, such as the lungs appearing to vibrate, and it was not clear if this was due to technical inconsistency or part of the lungs' functionality [99].

An AR application "ARIS" was suggested as an effective method to educate nursing practitioner students about asthma management in children [100]. The AR and Storytelling (ARIS) mobile application, which utilises learning theory alongside AR gamification, incorporates simulated dialogues and QR scanning and the ability for different scenarios to be incorporated into the platform. The authors [101] conducted a mixed-methods study to investigate nurse practitioner students' experiences of using ARIS, which was downloaded onto their iPads.The results concluded that nurse practitioner students were generally satisfied and motivated and increased confidence. However, some technical difficulties were reported, such as scanning the QR codes and iPad passwords (as the researchers provided them). Consequently, some participants pointed out that it would have been preferable if the application was downloaded onto their own devices. In addition, more realism was suggested by nurse practitioner students, such as the incorporation of asthma-related sounds [100].

An interactive AR application was developed for training purposes on nasogastric tube (NGT) insertion in nursing students [102]. This anatomy-augmented virtual simulation utilised a pre-recorded procedural video and 3D computer graphics, enabling nursing students to view the internal anatomical structures of a human body and manipulate the nasogastric tube accordingly by touching an iPad screen. In a mixed-methods study, nursing students were involved in data collection via open-ended questionnaires about their satisfaction and perception of incorporating the application into their curriculum. The results showed a high level of acceptance among nursing students, and visualising internal organs led to a better understanding of NGT insertion and memorising procedures. In addition, the application's user-friendly design (colours, easy navigation on the screen) was positively perceived. Furthermore, the application's ability to be used on iPads or smartphones was seen as an advantage by students, as they could access it even when they were not at the university's simulation unit [102].

An AR application (a marker-based) with the Leap Motion device (able to detect objects) was proposed for educating nursing students about hand anatomy [103]. This innovative educational pedagogy involves a computer desktop and a camera that captures the user's hand and sends the images to the computer software. The software consists of the "Unity 3D" game platform and the AR development kit "Vuforia", specifically for AR applications in mobile devices. In addition, the "Leap Motion" sensor device supports hand and finger movements. Among other healthcare students, nursing students were invited to evaluate this AR application and share their opinions and experiences. Nursing students reported positive attitudes towards the AR application, as it was easy to navigate, and they found it useful to implement in their nursing curriculum. Nevertheless, the outcomes were measured via a Likert scale questionnaire, possibly preventing the more detailed findings [103]. A Projected AR (P-AR) system was proposed for nursing education and pressure ulcer care in [104]. The system used 3D dynamic images augmented over a low-fidelity mannequin, which allowed students to observe anatomical structures or how skin conditions appear on different skin tones. Students could use their mobile devices, allowing collaborative learning and discussions. The system then uses the projector to display the previously detected information, recolouring and reshaping (i.e. retexturing) the images as they move and display them onto the mannequin, making them interactive. The P-AR was piloted on 27 (among 35 participants in total) undergraduate and graduate nursing students, and it was concluded that the P-AR promotes realism, interaction, engagement, and user-friendliness. Some improvements were suggested, such as improving the image qualities or interactive 3D features [104].

An AR application to enhance a better understanding of heart and lung patient assessment was piloted by [105]. The application uses the AR headset "Magic Leap One", which can apply a 3D organ model on a low-fidelity mannequin and assess internal organs. A QR code is allocated on the mannequin to enable the hologram position, and the hologram could be moved via the controller, which was in the position of the participants. A small number of participants were included (n=17), since this study was the first part of the system design. The nursing students' participants reported improved knowledge gains, with some suggested improvements, such as improving sound features. In the next stage of their system development, the authors planned to include a control group with more participants and test the system comprehensively [105].

An AR computer-based scenario for educating nurse practitioners' students was developed in [106]. The system included the Adobe Fuse CC to create the computed characters based on a bus accident emergency. The verbal scripts were implemented via ''Virtual People Factory 2.0'', which enabled student nurses to communicate with the characters. The experiences of nurse practitioner students were measured using the system. An HMD was worn by the participants, allowing them to see the patients virtually. The participants reported that realism and the feeling of practising important nursing concepts in a safe environment were the main advantages of using this AR technology. On the other hand, the limitations listed by participants were mainly related to technicalities such as Wi-Fi issues, which interfered with the verbal communication between users and virtual patients. In addition, some participants reported ''immersion sickness''. Overall, the system's usability requires improvement, including backup plans in case of a technical failure [106].

6) MIXED REALITY AND HOLOGRAMS

A 3D holographic application called ''Floating heart'' was developed to educate nursing students about heart anatomy and physiology [107]. A hand gesture recognition technology was implemented and projected onto the cardiovascular structure developed by 3D scanning and converted to a 3D layer object. The system enabled images with different angles to be viewed and manipulated, as the interactive system could detect hand movements via a Leap Motion sensor. The floating heart was evaluated by nursing students, resulting in overwhelmingly positive opinions, including reducing the need for imagination and creating a concrete impression due to the ability to view heart images from different angles. Nursing students highly appreciated the incorporation of 3D images, as, for example, they could observe blood flow and, therefore, memorise it easily. Nevertheless, the authors recognised the need to examine the effectiveness of this holographic 3D application in terms of nursing students' knowledge gains [107].

An MR application could be a useful technology to warn student nurses of an emergency, such as a fire in a surgical room [108]. Examining the technical and non-technical skills of nursing students in situations like fire in the workplace was the authors' aim in their research study [108]. In their study, an AR headset, ''Magic Leap One'', allows the nursing students to perform physical acts, and the glasses' features simulate smoke's visual effects. The fire simulation is activated by an instructor in a control room, who had the controller installed by the student. The instructor could join the AR experience with the student via Wi-Fi. Per the scenario, the instructor activates the fire and nursing students respond accordingly. The nursing students recruited to evaluate the application had generally positive experiences but reported that more features, such as smell or sound, should be implemented for more realistic scenarios. In addition, some interesting opinions emerged that the fire should have been a surprise instead of the pre-defined step of the scenario that was known to all participants [108].

A hologram-based scenario of an adult patient admitted to the emergency room following a bike accident was suggested as a beneficial method in nursing education [109]. Hololens (a head-mounted MR device) and HoloPatient applications were used, as the authors aimed to explore how MR, specifically HoloLens, can enhance clinical reasoning in nursing students. The results of the mixed-method study concluded that the hologram optimised learning experiences. The realism of the situation and the ability to view and assess the patient were among the top advantages shared by nursing students. Drawbacks were the inability to interact with the patient and technical issues, such as poor audio or visuals. The participants were not pre-briefed about the patient condition in this study, which the authors purposely chose to enhance student nurses' clinical experiences and judgment. Participants' demographics were not collected, which is reported as a limitation by the authors [109].

An MR application to explore nursing students' learning experiences was proposed in [110]. The application consisted of the Microsoft Hololens headset, which utilises an interaction between the user and computer within the MR settings and the Holopatient application. A volumetric 360-degree video and a patient presenting in the emergency room with anaphylactic shock were the foundation of the hologram. Collaborative learning was implemented with peers when one member wore the Microsoft Hololens and reported their assessment to colleagues who documented it. The roles were then reversed. The results were highly positive, with nursing students describing the visualisation of the patient but reporting that creating more memorable scenarios would further enhance their learning experience. The hologram was also helpful in identifying gaps in nursing students' assessment knowledge, and they were able to reflect on better practices. Some participants reported improved confidence and being able to observe the situation in a safe environment. All participants stated that they would like to work again with the hologram. However, it was noted that unfamiliarity with the application might have impacted the learning process for some participants. The authors recommended further research to focus on the comprehensive understanding of the use of holograms for educational gains in nursing [110].

A head-mounted MR tool, ''HoloLens'', was implemented into the HoloPatient application in [111]. The MR application was called ''HoloPatient: COVID-19'' and was designed by Health Education England (HEE) and the National Health Service (NHS) and was explicitly addressed to care for patients with COVID-19, presenting four stages of the disease. The authors collected qualitative data from nursing students about their experiences using this MR application. All participants were divided into seven focus groups, presented with a simulation lasting for one hour, and gave their opinions via the ZOOM platform. The system allowed the hologram view of a virtual patient with COVID-19, and nursing students could recognise and monitor COVID-19's signs and symptoms. They could assess breathing and heart rate and have the patient's chart beside them for clarity. Participants valued collaborative learning, as they could communicate with their colleagues and get a second opinion on a nursing management plan. Participants felt enhanced realism and safe to make mistakes in a protected environment, which led to optimised learning experiences. However, some drawbacks were reported, where the lack of patient interaction was the main criticism. Similarly, the lack of physical space in the room did not allow nursing students to reposition the patient as it could have been in a real-life situation. Some participants reported the room set up as 'unrealistic', as they were not asked to wear protective clothing, and no other beds were around. In addition, technical issues, such as not having a robust Wi-Fi connection and phone incompatibility, were reported. Suggestions for improvement were adding features which will allow patients to talk, information on infection control to be displayed, and the inclusion of patients in different age groups with COVID-19. HoloLens supports distance learning; however, this study was conducted in a classroom. Therefore, the authors recommended future studies examining nursing students' experiences in remote learning settings [111].

The benefits of the HoloPatient MR application in remote environments were explored in [112]. The authors assessed interdisciplinary communication in a virtual healthcare environment. A facilitator wore the Hololens, which projected a scenario of a patient with ischemic shock symptoms. The 'patient' was visible to the participants in real-time. The online mode allowed an interactive discussion and collaborative learning among nursing and medical students participating in this study. The results showed increased student satisfaction, with nursing students being more satisfied than medical students. However, the authors only examined the immediate post-test effects [112].

7) HAPTICS

The original Low-Cost Needle Insertion Simulator "LCNIS" was redesigned by [113], and the authors also tested it on real users. It initially consists of a physical device for needle insertion, which proved a natural feeling of insertion through the skin layers of a human via a haptic cartridge. The authors redesigned it, which is much more user-friendly. Also, a 'patient' was introduced in the computer user interface to increase realism, and options to store users' attempts and tutorials were added for users. The user interface gives options and feedback on needle insertion. However, it was only a medium-fidelity prototype, and only certain features were functional. Nevertheless, nursing students were interviewed and reported real-life-like experiences as students could see the 'patient' facial expressions while holding the 'needle' and administrating the 'medication' [113]. A haptic device with mixed reality (HMR-IV) was designed to enhance nursing students' intravenous cannulation' skills. The system consisted of two haptic devices (Geomagic touch and Dexmo) and the "HoloLens 2" MR glasses [114]. In addition, a haptic glove was tracked via the implementation of two depth sensors (Leap Motion and HoloLens), resulting in virtual hand-forced sensational feedback. A 3D mesh model was applied to create the graphics of the needle, the human and the veins. Nursing students were approached to share their experiences when utilising the HMR-IV system. The finding concluded high acceptance, easiness and realistic experiences among the participants. In addition, a low rate of frustration was measured, although with the biggest difference between novices and experts (higher), which the authors speculated might have been due to the age differences and exposure to technology in the participants with expert cannulation skills. However, the system experienced some technical issues, such as freezing of the glove's position, which the authors noted as the biggest limitation of the proposed system [114].

8) MULTIMODAL SYSTEM

An extended reality (XR) technology incorporating AR and smart glasses (Vuzix) supporting touchpads and voice recognition was proposed for nursing education in the context of intradermal injection administration and blood transfusion [115]. The system does not need additional equipment, as it consists of a display (graphical user interface) which could be used if nursing students need guidance or additional information. Thus, nursing students could navigate by manipulating the touchpad (positioned up/down/left/right). In addition to the support of Wi-Fi and Bluetooth networks for remote collaboration. The authors performed a qualitative usability test with observations. Most nursing students reported high satisfaction, with the main themes being interesting and convenient training experiences. In addition, the increase in memory regarding the learning objectives and increased self-efficiency were reported. However, some participants reported being more focused on learning how to operate the device than on the learning process. In addition, negative experiences were associated with the sensor being "too sensitive" to touch, resulting in some degree of frustration. Finally, the authors concluded that due to the increased popularity of smart glasses, new and more innovative smart glasses which could overcome the limitations of utilising Vuzix Blade could be more suitable for nursing education [115]. A VR game-based with haptics for urinary was implemented to enhance psychomotor skills of nursing students for urinary catheterization [116]. The system consisted of 3D headgear and interactive gloves facilitating haptic feedback. The authors conducted a mixed-methods pilot study, where a questionnaire with close-ended and open-ended options was distributed among nursing students. Overall, there were positive opinions, including the willingness of nursing students to practice urinary catheterisation via the proposed methods. All participants agreed that utilising the system will lead to correct catheter insertion due to the ability to practice in a safe environment. However, post-practice results revealed that just over half of the participants demonstrated effective knowledge of urinary catheterisation. The authors recognised the need to improve the VR haptic device, such as providing immediate feedback. In addition, there was a need to ensure the system's accessibility by the students at any time and from anywhere to enhance their self-efficiency in nursing education [116]. The VR Sterile Urinary Catheter Insertion Game "VR SUCIG" was developed by nursing educators and a computer game specialist to promote better catheterisation practices in nursing students [117]. The game consisted of an HMD device, "Oculus Rift", immersing learners in an exam room (virtual), where the patient (3D mannequin) was able to be downloaded onto a computer. Also, the haptic device enabled the learners to move objects in the virtual environment by hand gestures and a camera (Leap Motion), which captured their gestures. The game followed classic catheterisation techniques, such as aseptic techniques, sterile water fills, etc. The game was evaluated by faculty members and nursing students from eight American universities and one Australian university. Participants reported that the game component increased their motivation, resulting in repetitive practices and, therefore, increased confidence. Nevertheless, the game's usability was rated medium due to technical issues such as objects appearing unexpectedly on the screen, causing confusion and frustration for some participants [117]. An AR application with haptics was developed to educate student nurses about oedema (which causes body tissue swelling) by [118]. The AR headset is supported by "Magic Leap", which presents oedema on a leg, and a haptic device supported by "Geomagic Touch". "Geometric Touch" is a time of controller that allows the user to hold a pen-like device and feel the screen-based 3D objects. Both the haptic device and the leg have a script which enables deformity of the leg when touched by users and documents the depth and palpation of the portion depending on the touch. Although it was seen as an exciting concept by nursing students, according to the authors, the object's texture cannot be transmitted via haptic devices. Also, some concerns about the physical characteristics of the hardware, such as headset weight, were seen as a limitation [118]. A VR simulation with haptics, called "Leopold's Manoeuvres VR", to monitor fetus development by palpating a "human abdomen" was developed by [119]. A Sense Glove worn by the user allows haptic feedback in force and vibration. The VR also creates a sense of reality using the HTC VIVE HMD and a Unity 3D platform. The system was tested on nursing students, who were extremely enthusiastic about it and reported high student satisfaction. However, the noise caused by the glove distracted the users from their immersive state. It also was reported that the glove weighed too much [119].

A multimodal approach incorporating non-immersive VR for airways management was developed with the "Unity game engine" and "Acadicus tool" [120]. The equipment needed was an "Oculus Rift Touch VR Headset Bundle for nursing students" and a personal desktop computer. This VR management tool consists of step-by-step instructions about basic airway management protocol, and student nurses were able to receive directions from the headset speakers through a previously implemented voiceover guide while at the same time receiving haptic feedback. Thus, nursing students were exposed to touch, audio and visual stimuli when interacting with the system. Nursing students and faculty piloted This VR airway laboratory, resulting in high acceptance. Furthermore, VR sickness was not experienced by any of the participants [120].

A desktop VR simulation system incorporating an AI component resulted in the development of the AI-enabled VR Simulation (VRS) [121]. This VRS consisted of a virtual ward in a hospital, a doctor who was an AI agent, a nurse (avatar), a static patient, and a computer as an alternative to communicating with the AI doctor. The aim was to exercise communication practices between teams and evaluate nursing students' experiences. The results showed that overall, the nursing student participants were delighted with the learning experience but still found the interaction with the AI doctor strange and unusual, specifically the emotional part and the body language. The authors planned to incorporate chatbots with NLP features [121].

An AI concept was incorporated into developing a 3D immersive VR serious game with a patient's avatar to emphasise communication's importance in nursing undergraduate education [122]. The system was named "Comunica-Enf" and used a human instructor in real-time to set the commands via a computer keyboard. Undergraduate nursing students and educators evaluated the system by completing a heuristic evaluation. The results were mostly positive, with nursing students reporting a suitable environment for practising real-life skills. Nevertheless, the authors noted that the most prominent ethical consideration challenging to overcome is embracing AI's advantages without neglecting the human factor and natural interpersonal relations [122].

VI. RESULTS

This section presents the results of the study characteristics overall and the results of the studies' quality appraisal. Furthermore, based on the convergent segregated approach, the quantitative findings are first described, followed by the qualitative findings. Finally, qualitative and quantitative findings are integrated per [35].

A. STUDY CHARACTERISTICS

A total of 78 studies from 20 different countries (Figure 4) were included in this SLR. In addition, most articles were found in Scopus, followed by CINAHL Complete and PubMed databases, as shown in Figure 5. All 78 studies were explored to answer RQ1, while the studies addressing the quantitative data (i.e. addressing RQ2) are RCTs (n=14) and Quasi-experimental studies (n=23). The qualitative data addressing RQ3 was retrieved from 41 studies with a qualitative component. The majority were qualitative observational studies n=14), mixed methods studies (n=15), pilot studies with qualitative components (n=7). Moreover, conference papers (n=5) were also included as suggested

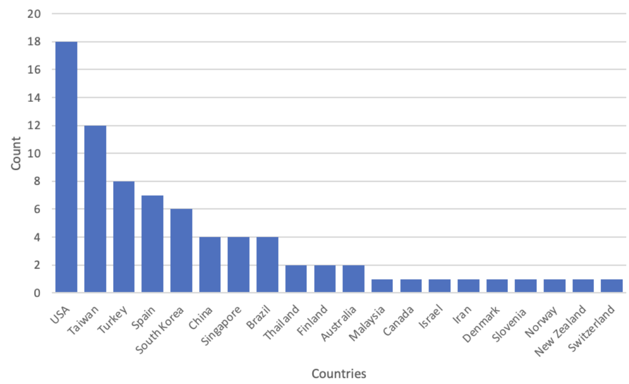

FIGURE 4. Studies distribution per country.

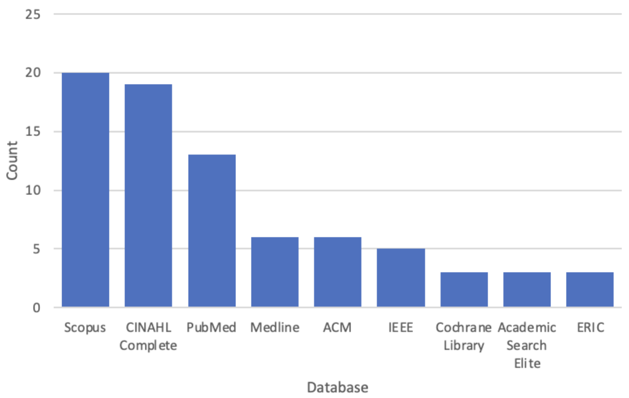

FIGURE 5. Studies distribution per database.

by [123], including grey literature that could significantly improve the robustness of a systematic review [123].

B. METHODOLOGICAL QUALITY OF THE INCLUDED STUDIES

In RCTs, risk of bias can arise from the randomisation process, deviations from intended interventions, lack of reporting of missing data, inappropriate measurements of the outcomes and inappropriate selection of the results report [41]. As per Cochrane risk of bias tool, each RCT is assessed (via signalling questions) for potential risk of bias, and results are automatically generated in green (low risk), yellow (some concerns), and red (high risk) as per [41]. Following the Cochrane risk of bias tool [41], this SLR reported some concerns about the deviations of intended intervention (i.e. reporting single or double blinding) and selection of the reported results. Consequently, one RCT [124] was excluded from this SLR following the Cochrane risk of bias tool. On the other hand, the randomisation process, missing data outcomes and measurement of the outcomes resulted in a high risk of bias. Moreover, the overall methodological quality of the RCTs included for assessment in this SLR is medium. These results are presented in Figure 6 and Figure 7.

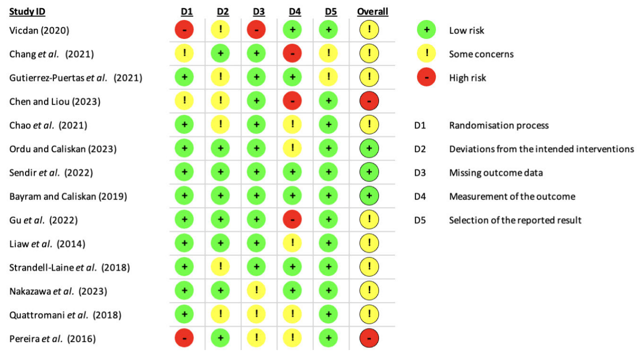

FIGURE 6. Quality appraisal of the RCTs.

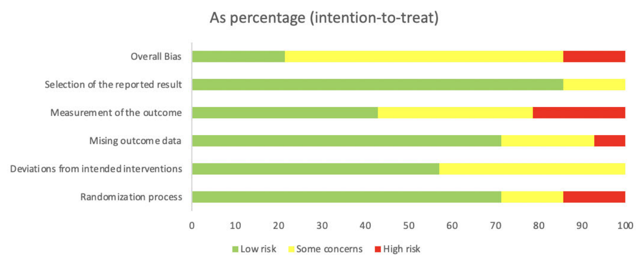

FIGURE 7. Overall representation of bias RCTs.

Table 3 provides the results of the quasi-experimental studies' quality appraisal (i.e. Yes, No, Unclear and N/A) against 9 Questions (provided in Table 3's footnote) as per JBI appraisal tool for quasi-experimental studies [42]. The main issue identified with the quality appraisal of the quasi-experimental studies was incomplete reports on participants' characteristics between control and experimental groups. However, no studies with quasi-experimental designs were excluded.

Table 4 provides the results of the quality appraisal of qualitative studies (i.e. Yes, No and Can't Tell) against 10 Questions (provided in Table 4's footnote). Some issues were found regarding the studies reporting the qualitative findings (illustrated in Table 4). These were limited reporting on ethical considerations, research instruments (i.e., close-ended questionnaires for nursing students' experiences) and incomplete or lack of reporting recruitment strategies. As a result, one study, [125], was excluded.

C. QUANTITATIVE FINDINGS

This section includes the findings from the quantitative data by presenting the results of RQ1 and RQ2.

1) RQ1.HOW HAVE COMPUTER-AIDED NURSING PEDAGOGIES EVOLVED THROUGHOUT THE PRE AND POST-COVID-19 ERA ?

This research question includes the characteristics of all 78 articles and produces overall findings. Overall, there is an increasing publication trend between 2013-2023, with more than 60% before and after the COVID-19 pandemic,

TABLE 3. Results of the quasi-experimental studies quality appraisal.

Authors	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
[43]	Yes	Unclear	Yes	Yes	Yes	N/A	Yes	Yes	Yes
[44]	Yes	Unclear	No	Yes	Yes	N/A	Yes	No	Yes
[46]	Yes	Unclear	No	Yes	Yes	No	Yes	Yes	Yes
[47]	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
[48]	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes
[49]	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes
[50]	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
[53]	Yes	Unclear	No	Yes	Yes	Unclear	Yes	No	Yes
[54]	Yes	Unclear	No	Yes	Yes	Yes	Yes	Yes	Yes
[55]	Yes	Unclear	Yes	Yes	Yes	Unclear	Yes	Yes	Yes
[56]	Yes	Unclear	No	Yes	Yes	N/A	Yes	Yes	Yes
[57]	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes
[63]	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes
[64]	Yes	Unclear	No	Yes	Yes	N/A	No	Yes	Yes
[65]	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
[66]	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No
[69]	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes
[71]	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
[72]	Yes	No	Yes	Yes	Yes	N/A	Yes	Yes	Yes
[73]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
[75]	Yes	No	Yes	Yes	Yes	N/A	Yes	Yes	Yes
[76]	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes	Yes
[80]	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

Q1. Is it clear in the study what is the 'cause' and the 'effect' (i.e., there is no confusion about which variable comes first)?
Q2. Were the participants included in any comparisons similar?
Q3. Were the participants included in any comparisons receiving similar treatment/care other than the exposure or intervention of interest?
Q4. Was there a control group?
Q5. Were there multiple measurements of the outcome, both pre and post Intervention/exposure?
Q6. Was follow-up complete, and if not, were differences between groups in terms of their follow-up adequately described and analysed?
Q7. Were the outcomes of participants included in any comparisons measured in the same way?
Q8. Were outcomes measured reliably?
Q9. Was appropriate statistical analysis used?

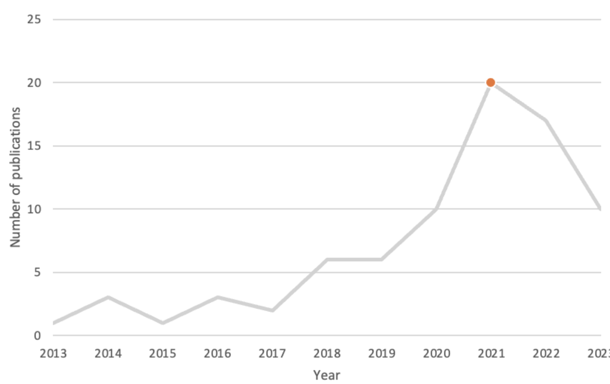

FIGURE 8. Number of publications between 2013-2023.

with 15 publications before from 2013-2018 (pre-COVID-19) and 63 publications between 2019-2023 (during and post-COVID-19). The years between 2013-2017 mark a fluctuation in number of publications, followed by a steady increase, reaching the highest peak in 2021. Then, a drastic fall is noticed in the following 2 years, as seen in Figure 8.

From 2013 - 2023, mobile applications as nursing pedagogies were generally fewer than desktop systems designed for education nursing students. However, it could be observed that the post-COVID-19 era addressed mobile applications embedded with VR and AR compared to the pre-COVID-19 era. In addition, the effectiveness and acceptability of AI-enabled systems and chatbots, multimodal pedagogies and smart glasses have only been studied in nursing education in the post-COVID-19 era. These are presented in Table 5 and Table 6 table chronologically, including the study and pedagogy types.

Most studies included undergraduate nursing students, and only [83], [100], [106] examined post-graduated nursing students. Various existing nursing pedagogies were identified for the period between 2013-2023. These are illustrated in Table 7 (quantitative data) and Table 9 (qualitative data), including the authors, the type of technology/pedagogy used, and their purpose in nursing education. Although interactive mobile applications and computerised systems are still relevant, VR and AR appeared as emerging pedagogy, with VR being the most predominant learning environment. In addition, MR holograms and haptic devices in nursing education have been investigated by some researchers. Combining two or more types in one system is common (i.e. a multimodal system), such as combining VR technology and haptics, AR and haptics, etc. The concept of AI was mainly presented via chatbots.

The concept of gamification and serious games were adequately explored and mainly emerged in computerised systems [85], [86], [90], [91], [126], VR [87], [88], [98], [117] and AI [122]. Findings from all 78 studies based on cognitive (knowledge-based), affection (emotion-based) and psychomotor dimensions (actions-based) describe an unequal representation of articles addressing the three domains, with the affection domain being represented by only two authors.

2) RQ2. HOW EFFECTIVE ARE THE IDENTIFIED COMPUTER-AIDED NURSING PEDAGOGIES COMPARED TO TRADITIONAL NURSING PEDAGOGIES?

The effectiveness of computer-aided nursing pedagogies in this SLR was measured among 37 quantitative studies (RCTs and quasi-experimental studies), including a total of 4306 nursing students ($n = 2376$ participants in the experimental groups, and $n=1930$ participants in the control groups). The measures of the effectiveness of the computer-aided nursing pedagogies against traditional nursing education methods can be seen in Table 8. The outcomes of knowledge acquisition (cognitive domain) and skills acquisition (psychomotor domain) were predominantly measured in this SLR. However, knowledge retention (long-term knowledge gains) was only accessed by [45], [50], [57], [61], [65], [66], and [79]. In contrast to cognitive and psychomotor domains, the affective domain was only examined by [70] among the 37 studies examining computer-aided nursing education pedagogies' effectiveness. Most of the

TABLE 4. Quality appraisal of qualitative studies.

Authors	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
[81]	Yes	Yes	Yes	Yes	No	Can't tell	Yes	Yes	Yes	Yes
[82]	Yes	Yes	No	Yes	No	Can't tell	Yes	Yes	No	Yes
[83]	Yes	Can't tell	Can't tell	No	Can't tell	Yes	Can't tell	Yes	Yes	Yes
[84]	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes
[85]	Yes	Can't tell	Can't tell	Yes	Yes	No	Can't tell	Yes	Yes	Yes
[86]	Yes	Yes	Can't tell	Yes	Yes	No	Can't tell	Yes	Yes	Yes
[87]	Yes	Yes	Can't tell	No	No	Yes	Yes	Yes	Yes	Yes
[88]	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes
[89]	Yes	Yes	No	Can't tell	Yes	Can't tell	Can't tell	No	Yes	Yes
[90]	Yes	Yes	Can't tell	Yes	Yes	Yes	Can't tell	No	Can't tell	Yes
[91]	Yes	No	Can't tell	No	Can't tell	Can't tell	Can't tell	Yes	Yes	Yes
[92]	Yes	Yes	Yes	Can't tell	Yes	No	Can't tell	No	Yes	Yes
[93]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes
[94]	Yes	Yes	Yes	Yes	Yes	No	Yes	Can't tell	Yes	Yes
[95]	Yes	Yes	Yes	Yes	No	Can't tell	Yes	Yes	Yes	Yes
[96]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	No	Yes	Yes
[97]	Yes	Yes	Yes	Can't tell	Yes	No	Yes	Yes	Yes	Yes
[98]	Yes	Yes	Can't tell	No	No	Can't tell	Yes	Yes	Yes	Yes
[99]	Yes	Yes	Yes	Yes	Yes	Can't tell	Can't tell	No	Yes	Yes
[100]	Yes	Yes	Yes	Yes	No	Can't tell	Yes	No	Yes	Yes
[102]	Yes	Yes	No	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes
[103]	Yes	Yes	No	Yes	No	Can't tell	Can't tell	No	Yes	Yes
[104]	Yes	Yes	Can't tell	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes
[105]	Yes	Yes	Can't tell	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes
[106]	Yes	Yes	Yes	Can't tell	Can't tell	No	Yes	Yes	Yes	Yes
[107]	No	Yes	Yes	Yes	Yes	Can't tell	No	No	Yes	Yes
[108]	Yes	Yes	Can't tell	Can't tell	Yes	No	Yes	Yes	Yes	Yes
[109]	Yes	Yes	Yes	Can't tell	Yes	No	Yes	Yes	Yes	Yes
[110]	Yes	Yes	Can't tell	Can't tell	Yes	No	Yes	Yes	Yes	Yes
[111]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
[112]	Yes	Yes	Can't tell	Can't tell	Yes	No	Yes	Can't tell	Yes	Yes
[113]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
[114]	No	Yes	Yes	Yes	No	Can't tell	Yes	Yes	Yes	Yes
[115]	Yes	Yes	Yes	Yes	No	Can't tell	Yes	Yes	Yes	Yes
[116]	Yes	Yes	No	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes
[117]	Yes	Yes	Yes	No	Can't tell	No	Yes	Yes	Yes	Yes
[118]	Yes	Yes	Can't tell	Can't tell	Yes	Can't tell	Can't tell	No	Yes	Yes
[119]	Yes	Can't tell	No	Can't tell	Yes	Can't tell	Can't tell	No	Yes	Yes
[120]	Yes	Yes	No	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes
[121]	Yes	Yes	Yes	Yes	Yes	yes	Can't tell	Yes	Yes	yes
[122]	Yes	Yes	Can't tell	Can't tell	Yes	No	Yes	Yes	Yes	Yes

Q1. Was there a clear statement of the aims of the research?
Q2. Is a qualitative methodology appropriate?
Q3. Was the research design appropriate to address the aims of the research?
Q4. Was the recruitment strategy appropriate to the aims of the research?
Q5. Was the data collected in a way that addressed the research issue?
Q6. Has the relationship between the researcher and participants been adequately considered?
Q7. Have ethical issues been taken into consideration?
Q8. Was the data analysis sufficiently rigorous?
Q9. Is there a clear statement of findings?
Q10. How valuable is the research?

studies in this SLR concluded the superiority of their proposed nursing pedagogies against traditional educational nursing methods, specifically regarding knowledge and skills acquisition.

Partly different outcomes in comparisons of the two groups were reported by [69], who investigated a VR simulation with the haptic device, where the experimental group had significantly higher satisfaction and self-efficiency but no differences in knowledge acquisition. No significant difference between the two groups (regarding skills acquisition and self-confidence) was found by [76], who examined a VR simulation with a haptic device. Likewise, similar clinical reasoning and self-efficiency between experimental and control groups were found by [57], but the experimental group had higher student satisfaction when examining an interactive mobile application. Similarly, no significant differences in knowledge and clinical reasoning were reported by [64], who examined an AI-enabled chatbot. However, better confidence and student satisfaction were noted in the group using the AI-enabled chatbot [64].

No differences between the two groups were found by [79] (mobile chatbot), [59] (Instagram mobile application)

TABLE 5. Computer-aided nursing pedagogies in the pre-COVID-19 era.

Author	Year	Pedagogy type	Study type
[45]	2014	Desktop-based VR	RCT
[96]	2014	Interactive mobile application	Qualitative
[99]	2014	AR System	Qualitative
[81]	2015	Desktop-based system	Qualitative
[55]	2016	Mobile interactive application	Quasi-experimental
[53]	2016	Mobile application	Quasi-experimental
[82]	2017	Desktop-based system	Qualitative
[65]	2017	Desktop-based VR	Quasi-experimental
[80]	2017	VR with Haptics	Quasi-experimental
[116]	2018	VR with Haptics	Qualitative
[102]	2018	Interactive AR	Qualitative
[103]	2018	AR	Qualitative
[107]	2018	Hologram and MR	Qualittaive
[52]	2018	Mobile application	RCT
[51]	2018	Mobile application	RCT

and [73] (AR-enabled mobile application). In addition, no significant differences between the two groups were found by [80] who tested a VR simulator with a haptic device, and [51] who studied a mobile application. Likewise, [45] and [52] who investigated desktop-based VR and mobile applications did not find significant differences between the two groups. In this SLR Hedge's g score was calculated utilising a spreadsheet proposed by [127], based on the reported t-tests by the authors in this SLR. As emphasised by [127] variations in sample sizes and effect size among studies in a SLR could negatively impact the validity and generalisability of the quantitative findings. Continuous data were extracted from the studies in terms of Mean, Standard Deviation (SD) and group size [128]. The primary outcomes of interest were knowledge and skills acquisition, and they are reported as a change from baseline, as suggested by [128]. This is evident in Table 10, where Confidence Intervals (CI) and p values were reported as emphasised by [129], and the Hedges'g score(g)was calculated, resulting in a range from small, medium and large effects [128]. The results of Table 10 showed variations in sample sizes, ranging from 36 participants to 635 participants in the studies. Furthermore, the effect sizes of individual studies ranged from g=0.0 to g=9.4. Consequently, the generalizability and reliability of the findings suggest that computer-aided nursing pedagogies' effectiveness might be compromised.

Two studies ([56], [73]) are not included in Table 10, as their authors did not report Mean and SD in their findings, and their statistical values were reported based on Confidence Intervals (CI) and p values.The authors in [56] concluded CI (−0.923, 0.298) based on 95% CI and p=0.352 in the control group compared to the CI (−0.769, 0.280) based on 95% CI and 0.305. In addition, [73] reported the independent sample t-test (t(30)=1.846, where p=0.075 concluding no significant differences between the two groups in terms of knowledge gains.

D. QUALITATIVE FINDINGS

This section presents the qualitative findings from articles examining nursing students' experiences and opinions, explored in RQ3.

1) RQ3. WHAT ARE NURSING STUDENTS' EXPERIENCES AND OPINIONS ABOUT COMPUTER-AIDED NURSING PEDAGOGIES?

Addressing RQ3, through our extensive research, we have categorised nursing students' experiences into positive and negative experiences, which are detailed below. Positive experiences: (1) Immediate feedback, (2) realism, (3) ability to practice in a safe environment, (4) ability for collaborative learning, (5) positive attitudes towards gamification and serious games in nursing pedagogies. Negative experiences: (1) lack of more interactive features, such as voice recognition and NLP; (2) nursing students' unfamiliarity with the proposed pedagogies; (3) lack of emotional recognition, realistic conversations and interaction; (4) technical issues such as phone incompatibility or poor Wi-Fi connection, (5) distraction from learning experiences (noise production from the equipment), (6) heavy weight of some equipment (VR/AR glasses) and immersive sickness (wearing immersive VR sets). Some participants reported ethical concerns with using AI-enabled pedagogies, such as fears of erasing the affectionate component from the nursing profession. Even though there were concerns about maintaining the 'human factor' while using AI, some authors still planned the implementation of more AI features to replace manual calculation due to convenience [122]. Enthusiasm for new technology use in nursing students emerged with increased motivation, positive attitudes, and a high acceptance rate in general. Collaborative learning (where applicable) was seen as a significant plus due to increased communication skills and reduced anxiety [130]. The immediate feedback from some of the proposed pedagogies was also seen as

TABLE 6. Computer-aided nursing pedagogies in the post-COVID-19 era.

Author	Year	Pedagogy type	Study type
[44]	2019	CAI	Quasi-experimental
[91]	2019	Mobile application	Qualitative
[67]	2019	Mobile, game-based VR application	RCT
[94]	2019	AI Desktop-system	Qualitative
[108]	2020	MR and Holograms	Qualitative
[110]	2020	AR system	Qualitative
[120]	2020	Non-immersive VR	Qualitative
[100]	2020	Computerised VR with haptics	Qualitative
[76]	2020	VR Desktop system	Quasi-experimental
[98]	2020	Desktop-based system	Qualitative
[59]	2020	Instagram mobile application	RCT
[83]	2020	Desktop system	Qualitative
[46]	2020	Desktop-based system	Quasi experimental
[47]	2020	Desktop-based game system	Quasi-experimental
[43]	2021	Computed Anatomage table (AT) technology	Quasi-experimental
[84]	2021	Desktop system	Qualitative
[50]	2021	Mobile application	Quasi-experimental
[56]	2021	Mobile application	Quasi-experimental
[61]	2021	Mobile application	RCT
[122]	2021	AI-Chatbot	Qualitative
[87]	2021	VR Desktop System	Qualitative
[89]	2021	VR Mobile application	Qualitative
[97]	2021	VR desktop system	Qualitative
[69]	2021	Computerised VR with haptics	Quasi-experimental
[71]	2021	Mobile application with AR	Quasi-experimental
[73]	2021	AR-enabled smartphone application	Quasi-experimental
[106]	2021	AR	Qualitative
[77]	2021	Mobile application with VR and haptics	RCT
[79]	2021	Multimodal	RCT
[113]	2021	Haptics desktop system	Qualitative
[117]	2021	VR with haptics	Qualitative
[119]	2021	VR with haptics	Qualitative
[118]	2021	AR application with haptics	Qualitative
[75]	2021	3D holograms	Quasi-experimental
[115]	2021	XR smart glasses	Qualitative
[109]	2021	MR and holograms	Qualitative
[112]	2022	MR and holograms	Qualitative
[105]	2022	AR with holograms	Qualitative
[93]	2022	AI Desktop system	Qualitative
[78]	2022	Haptics	RCT
[104]	2022	AR Desktop system	Qualitative
[72]	2022	AR-enabled smartphone application	Quasi-experimental
[88]	2022	VR Desktop system	Qualitative
[62]	2022	Mobile chatbot	RCT
[63]	2022	AI chatbot	Quasi-experimental
[64]	2022	AI chatbot	Quasi-experimental
[92]	2022	AI chatbot	Qualitative
[54]	2022	Mobile application	Quasi-experimental
[60]	2022	Game-based interactive mobile application	RCT
[66]	2022	Mobile VR educational program (MVREP)	Quasi-experimental
[90]	2022	Mobile application	Qualitative
[95]	2022	Mobile application	Qualitative
[49]	2022	Desktop neonatal serious games simulation (NR-SGS)	Quasi-experimental
[85]	2022	Desktop system	Qualitative
[86]	2022	Desktop system	Qualitative
[48]	2022	Desktop 3D system	Quasi-experimental
[57]	2023	Interactive mobile application	Quasi-experimental
[68]	2023	An app incorporating VR	RCT
[121]	2023	AI system	Qualitative
[74]	2023	AR mobile application	RCT
[70]	2023	AR enabled system	RCT
[111]	2023	MR and holograms	Qualitative
[114]	2023	Multimodal	Qualitative

TABLE 7. Computer-aided nursing pedagogies tested against traditional nursing educational methods (Quantitative data).

Authors	Type	Purpose
[43]	Computed Anatomage Table (AT) technology	Anatomy teaching.
[44]	CAI system	Nursing care of diabetic pregnant patients.
[45]	Desktop-based VR	Improving clinical performance.
[46]	Desktop-based system	Electrocardiogram training.
[47]	Desktop-based game	Surgical nursing care.
[48]	Desktop 3D system	Cardiopulmonary resuscitation (CPR) administration.
[49]	Desktop neonatal serious games simulation (NR-SGS)	Cardiopulmonary resuscitation (CPR) in babies.
[50]	Mobile application	Chest tube nursing care.
[51]	Mobile application	Infusion pump manipulation.
[52]	Mobile application	Communication between nursing students and teachers.
[53]	Mobile application	Medication dose calculation.
[54]	Mobile application	Problem-solving activities.
[55]	Mobile interactive application	Problem-based learning practices.
[56]	Mobile application	Measuring Vital signs.
[57]	Interactive mobile application	Paediatric nursing education.
[59]	Instagram mobile application	Performing Intramuscular (IM) injections.
[60]	Game-based interactive mobile application	Flushing venous catheter.
[61]	Mobile application	Basic and Advanced Life support.
[62]	Mobile chatbot	Vaccination in pregnant women.
[63]	AI Chatbot	Learning anatomy.
[64]	AI Chatbot	Fetal monitoring in nursing education.
[65]	Desktop-based VR	Medication administration.
[66]	Mobile VR educational program (MVREP)	Surgical aseptic skills.
[67]	Mobile, game-based VR applications	Tracheostomy care.
[68]	Ann app incorporating VR	Teaching the nursing process.
[69]	Computarised VR with haptics	Scenario (nursing communication).
[70]	AR-enabled system	communication with patients with dementia.
[71]	Mobile application with AR	Intravenous injections administration.
[72]	AR-enabled smartphone applications	Pressure ulcers.
[73]	AR -enabled smart phone applications	Anatomy and physiology of the heart.
[74]	Augmented reality application	Paediatric first aid training.
[75]	3D hologram	Effectiveness on knowledge and skills acquisition.
[76]	Computerised VR with haptics	Intravenous injection insertion.
[77]	Mobile app, with VR, and haptic techniques	Nasotracheal care.
[78]	Haptics	Urinary Catheterisation
[79]	An app with VR, AR and haptics	Nasogastric tube feeding.
[80]	VR with haptics	Nasogastric tube placement.

a considerable advantage, along with realistic scenarios, situations and environments. Furthermore, nursing students' participants heavily criticised the lack of realism, such as the lack of body movement in a hologram or conversation with a virtual patient. On the other hand, the ability for interactive communication enhanced the realistic nature of some proposed systems. In gamification, feelings of competitive experiences (when the system provides a scoring grade (Kahoot!)), high motivation and a simplifier approach to understanding nursing theory were reported. Nursing students highly appreciated using their own devices as they provided privacy. In addition, some participants requested more memorable scenarios.

E. DATA SYNTHESIS

The overall effectiveness of the proposed nursing pedagogies in terms of knowledge and skills acquisition, nursing students' satisfaction, self-efficiency and self-confidence are supported by the generally positive attitudes towards the used computer-aided pedagogies and joyful experiences. The effectiveness of the systems against traditional nursing educational methods is likely correlated with the general

TABLE 8. Measurements of the effectiveness of computer-aided nursing education pedagogies against traditional methods.

Authors	Measures of effectiveness
[43]	Knowledge gains and student satisfaction .
[44]	Knowledge acquisition, student satisfaction and self-efficacy.
[45]	Knowledge and skills acquisition.
[46]	Knowledge and skills acquisition.
[47]	Knowledge acquisition.
[48]	Skills acquisition and students' confidence.
[49]	Knowledge and skills satisfaction and students' experiences.
[50]	Clinical reasoning and self-efficiency.
[51]	Knowledge acquisition and engagement level.
[52]	Self-efficiency, Competence.
[53]	Skills acquisition.
[54]	Skills acquisition.
[55]	Knowledge acquisition.
[56]	Skills and knowledge acquisition.
[57]	Clinical reasoning, self-efficiency and learning satisfaction.
[59]	Knowledge and skills
[60]	Skill performance, error incidence and the average performance attempts.
[61]	Knowledge, gameful experience.
[62]	Self-efficiency, learning experiences and academic knowledge.
[63]	Academic performance, critical thinking and learning satisfaction.
[64]	Clinical reasoning, knowledge, feedback satisfaction and students' confidence.
[65]	Knowledge acquisition.
[66]	Skill acquisition.
[67]	Knowledge and skills.
[68]	Knowledge about nursing diagnosis, goal setting and prioritising diagnosis.
[69]	Nursing knowledge, self-efficacy, and user satisfaction.
[70]	Affection skills.
[71]	Knowledge acquisition.
[72]	Knowledge and skill acquisition, learning determinants (in the experimental group).
[73]	Learning outcomes, student satisfaction, and system's usability.
[74]	Knowledge, skills, and self-confidence.
[75]	Knowledge and skills acquisition and student satisfaction.
[76]	Skill acquisition and self-confidence.
[77]	Knowledge, skills, learner satisfaction
[78]	Skills acquisition and student satisfaction
[79]	Knowledge, skills, confidence, and student satisfaction.
[80]	Knowledge and skills acquisition, acceptance.

satisfaction of nursing students. For example, in the studies where proposed pedagogies were superior to traditional methods, this was due to increased interest in learning [64] and students' satisfaction [79]. Moreover, the studies reported part differences between the experimental and control groups, or no differences in outcomes between the two groups, feelings of frustration and anxiety due to technical issues, poor Wi-Fi connection, and not enough time to familiarise themselves with the computerised educational system, or feelings of nausea (in case of wearing an AR headset). In addition, only 2 authors [81] and [117] examined participants with different demographics and included participants from more than one site (country). However, the authors did not measure how this can affect the results. Few authors raised concerns about the scales used to measure the outcomes.

F. UNEXPECTED FINDINGS

Although not pre-define as a research question, this SLR discovered that one of the main concerns of the authors was the time and resources needed to build and maintain some computer-aided nursing educational systems [63], [70], [71], [75], [77], [84], [87]. Moreover, two authors [48] and [56] recommended research to focus on applications applicable to areas with low-income and limited internet resources. These findings agree with the [2], who stated that when addressing the widespread application of technology in nursing education, nursing educators should consider nursing students from less privileged backgrounds where technical issues concerning internet connection exist.

VII. DISCUSSION

This section compares the studies' methodological quality and the three RQs' findings to related research.

The first research question (RQ1) examined how computer-aided nursing pedagogies evolved in the pre and post-COVID-19 era, including articles from 2013-2023.

The second research question (RQ2) included quantitative study designs to conclude nursing pedagogies' effectiveness against traditional educational practices.

Finally, the third research question (RQ3) investigated the qualitative component by examining how nursing students perceive computer-aided nursing pedagogies.

A. METHODOLOGICAL QUALITY OF THE STUDIES

Gender bias was noted in all studies included. However, this could be because nursing is a female-dominant profession. For example, 88.6% of nurses and health visitors in the United Kingdom (UK) are females [131]. Nevertheless, two studies included in this SLR did not find a correlation between sex/age and academic knowledge scores and gains [57], [59].

According to [132], failing to report missing data in RCTs leads to incorrectly presented conclusions because it is unclear how these missing values could have influenced the end results. In agreement with [14], in the RCTs, the authors did not mention missing data in their studies. Furthermore, a recent cross-sectional study examining the methodological quality of 200 RCTs concluded inadequate reports of missing data [133].

Moreover, limited report on blinding was the other issue identified during the quality appraisals of the RCTs in this SLR. As suggested by [134], blinding in trials occurs when the participants or the researcher/data analyst are unaware of which group has been assigned to the experiment (intervention), which might influence their behaviour or judgement [134]. Similarly, [17] found out in their SLR that most authors of RCTs did not report blinding. Consequently, the reported methodological biases in the RCTs might negatively impact the findings' reliability and credibility.

TABLE 9. Computer-aided nursing pedagogies used to examine student nurses experiences and opinions (Qualitative data).

Authors	Type	Purpose
[81]	Desktop-based system	Pre-term babies assessment.
[82]	Desktop-based system	Pain management education.
[83]	Desktop system	Scenario (communication between team members).
[84]	Desktop system	Scenario (team communication).
[85]	Desktop system	Interprofessional communication in nursing.
[86]	Desktop system	An escape room -an educational game with puzzles and hints.
[87]	VR desktop system	Cardiopulmonary bypass education.
[88]	VR desktop system	Communication for a patient with sepsis.
[89]	VR mobile application	Testing the system as an addition to blended learning in nursing education.
[90]	Mobile application	Goals and tips of keeping astronauts healthy in the international space station.
[91]	Mobile application	Monitor academic performance-enrich and evaluate a nursing subject.
[92]	AI- Chatbot Mobile application	To support student nurse library services.
[93]	AI Desktop system	Clinical decision making.
[94]	AI Desktop system	Scenarios (communication skills).
[95]	Mobile application	Diabetes management.
[96]	Interactive mobile application	Identifying patient's veins.
[97]	VR desktop system	Nursing communication.
[98]	VR desktop system	Prevention of needle stick injuries.
[99]	AR system	Lung anatomy and physiology.
[100]	AR system	Pediatric asthma management.
[102]	Interactive AR	Nasogastric tube insertion.
[103]	Augmented reality	Hand anatomy learning.
[104]	AR Desktop system	Pressure ulcers care.
[105]	AR(with hologram)	Heart and lung assessment.
[106]	AR	Scenario (triage).
[107]	Hologram and MR	Cardiovascular system education.
[108]	MR and holograms	Laptop Scenario (fire in a surgical room).
[109]	MR and holograms	Desktop system Scenario (bike accident resulting in emergency room admission).
[110]	MR and holograms	Scenario (ER with anaphylactic shock).
[111]	MR and holograms	Both mobile and desktop Scenario (care for the patient with COVID-19.
[112]	MR and holograms	Scenario (patient with ischemic shock).
[113]	Haptics Desktop system	Needle insertion.
[114]	Multimodal	Needle insertion.
[115]	XR Smart glasses	Practical skills (blood transfusion and intradermal injections).
[116]	VR and haptics	Urinary catheterisation.
[117]	VR (with haptics)	For urinary catheterisation practices.
[118]	AR application with Haptics	Condition recognition (Edema).
[119]	Haptics(with VR)	Monitor fetus development.
[120]	Non-immersive VR	Airway management.
[121]	AI	Communication skills between teams.
[122]	AI-Chatbot	Mobile application Communication skills.

Regarding the quasi-experimental studies' methodology, some authors reported the participants' characteristics and the recruitment process insufficiently. According to [133], this leads to selection bias because the outcome might not be associated with the intervention but with the participant's differences. This finding agrees with the findings of [14] and [42].

Similarly to the RCTs and quasi-experimental studies, the quality appraisal for the qualitative studies reported issues of incomplete report of recruitment strategies and ethical considerations.

Consequently, this SLR concludes the need for more rigorous research, leading to evidence-informed conclusions.

B. RESEARCH QUESTION 1

This SLR accounted for 78 primary studies published before, during, and after the post-COVID-19 era from 20 different developed countries, examining different aspects of computer-aided pedagogies in nursing education. In addition, the generalisability of the quantitative findings could be compromised, as computer-aided nursing pedagogies in developing countries might have different perspectives. It is important to note that developing countries might have completely different priorities (healthcare, social protection, regulatory support) during the COVID-19 pandemic [135], or beliefs and attitudes, pedagogical approaches or social

TABLE 10. Effect size of quantitative studies reported by Hedges's g score.

Author	Experimental group Mean	Experimental group Standard Deviation (SD)	Experimental group sample (n)	Control group Mean	Control group Standard Deviation (SD)	Control group sample (n)	Hedges'g score	95% Confidence interval (CI), M diff	t	df	*p*
[43]	64	2.4	503	68.9	1.9	132	2.1	[-4.51, 55.91]	-24.9	633	0.00
[44]	8.5	1.26	40	4.35	0.89	40	3.8	[0.31, 4.63]	17.01	78	0.00
[46]	86.33	0.48	36	80.33	0.77	36	9.4	[6.30, 78.30]	39.7	70	0.00
[45]	36.65	5.59	31	33.27	7.5	26	0.5	[6.95, 25.40]	1.9	55	0.06
[47]	43.2	3.61	135	43.6	4.62	129	0.1	[0.61,-34.50]	-0.78	262	0.44
[48]	52.11	3.87	28	51.18	5.3	28	0.2	[3.42, 41.92]	0.75	54	0.46
[49]	4.64	0.36	45	4.53	0.42	45	0.3	[0.27, -3.22]	1.33	88	0.19
[50]	64.54	7.27	53	59.47	7.17	54	0.7	[7.84, 54.07]	3.63	105	0.00
[51]	9	1.9	87	9	2.3	94	0.0	[0.62, 0.68]	0	179	1.00
[52]	45.55	18.15	52	49.23	21.79	50	0.2	[4.12, 29.96]	-0.92	100	0.36
[53]	8.14	1.67	50	5.02	3.21	50	1.2	[-0.58, 4.13]	6.1	98	0.00
[54]	69.03	4.28	30	61.9	8.11	30	1.1	[10.49, 57.98]	4.26	58	0.00
[55]	71.25	6.46	20	56.56	5.98	16	2.0	[18.91, 59.32]	7.07	34	0.00
[57]	61.66	9.83	77	61.97	10.15	86	0.0	[2.79, 50.87]	-0.19	161	0.84
[59]	17.33	3.04	69	18.1	1.9	69	0.3	[0.08, 8.78]	-1.8	136	0.08
[60]	89	5.214	77	89	1.634	77	0.0	[1.23, 80.07]	0	152	1.00
[61]	7.72	1.15	92	6.9	1.45	92	0.6	[-0.36, 1.2]	4.25	182	0.00
[62]	88.58	11.02	18	60.51	15.01	18	2.1	[36.99, 71.96]	6.4	34	0.00
[63]	87.9	11.33	16	62.32	14.95	16	1.9	[35.15, 70.62]	5.45	30	0.00
[64]	5.7	2.77	30	6	1.95	31	0.1	[0.93, -3.23]	-0.50	59	0.63
[65]	98	1.3	82	6	54	47	2.8	[74.71, 107.60]	11.7	127	0.00
[67]	18	1.8	43	17	1.6	43	0.6	[1.73, 9.57]	2.72	84	0.01
[68]	1798.6	283.4	51	1455.09	343.09	51	1.1	[467.16, 1667.30]	5.51	100	0.00
[69]	23.44	2.15	25	23.29	1.92	25	0.1	[1.31, 14.58]	0.26	48	0.8
[70]	117.65	10.58	21	115.47	12.84	17	0.2	[10.04, 102.09]	0.56	36	0.58
[71]	79.61	19	64	41.52	15	58	2.2	[44.20, 65.80]	12.34	120	0.00
[72]	6.08	2.26	72	5.23	2.38	65	0.4	[-2.4,1.64]	2.14	135	0.03
[74]	18.78	1.1	46	18.08	1.6	49	0.5	[1.26, 10.52]	2.50	93	0.01
[75]	68.88	9.93	40	62.85	11.25	39	0.6	[10.79, 56.42]	2.52	77	0.01
[76]	75.07	13.92	30	67.3	15.73	30	0.5	[15.45, 59.70]	2.03	58	0.05
[77]	80.9	9.12	50	74.4	9.61	50	0.7	[9.4, 68.7]	3.04	98	0.00
[78]	94.9	3.3	39	58.5	20.1	40	2.5	[42.3, 80.8]	11.3	77	0.00
[79]	11.73	1.86	22	11.91	2.04	23	0.1	[1.02, 2.86]	-0.31	43	0.76
[80]	40.1	5.9	40	41.3	5.2	39	0.2	[1.29, 29.91]	-0.96	77	0.34
[66]	17	0	22	14.50	3.75	18	1.0	[0.71, 4.29]	2.83	38	0.01

structures than in developed countries. Therefore, it is unclear if COVID-19 have prevented publications of computer-aided nursing pedagogies or if there is a minimal implementation of innovative nursing teaching strategy in developing countries. For example, a cross-sectional study including 480 nursing students from different European countries concluded that different levels of digital learning resource acceptance depend on the participants' demographics [136]. Although beyond the scope of this SLR, sociodemographic factors and their association with computer-aided nursing education pedagogies might be worth investigating in the future.

On the other hand, a drastic decrease in publication was noted from 2021 (the year with more publications) to 2022 and 2023. It could be speculated that these results occurred due to a temporary pause in research activities due to lockdown laws and social distancing measures. Even though the COVID-19 pandemic could be seen as a barrier to conducting research studies, the findings of this SLR suggest an increased interest in innovative nursing pedagogies. Moreover, an increasing publication trend was evident when comparing the pre and post-COVID-19 era. This aligns with [14], who concluded that the number of research studies in computerised nursing education pedagogy has raised [14]. Regarding study design representation, the RCTs pre-COVID-19 were significantly fewer than the RCTs post-COVID-19. Nevertheless, the RCTs were generally fewer than quasi-experimental studies and articles addressing qualitative components. This confirms the need for more RCTs in nursing research, as previously emphasised by [11] and [64].

The reviewed articles in this SLR presented a broad range of computer-aided pedagogies in nursing education, including VR, AR, MR and holograms, haptics, chatbots and multimodal systems. It was evident from this SLR that the post-COVID-19 era accommodated more innovative techniques such as AI-enabled systems and chatbots, multimodal systems and more interactive mobile applications incorporating gamification, AR and haptics. Incorporating types of technological pedagogies in nursing was the main requirement of the International Nursing Association for Clinical Simulation and Learning (INACSL) in 2020 [7]. Therefore, this SLR highlights that official bodies' requests are taken into consideration by researchers in the post-COVID-19 times. Nevertheless, most studies examined nursing education's cognitive and psychomotor aspects instead of the affective aspect. This finding agrees with [137], who concluded that the cognitive domain was mainly addressed in their SLR addressing game-based nursing education pedagogies.

C. RESEARCH QUESTION 2

The finding of this SLR demonstrates the overall effectiveness of computerised systems in knowledge and skills acquisition and self-efficacy. These findings agree with [14] and [15], who concluded that innovative technology pedagogies are highly effective in nursing education. However, the findings of this SLR are interpreted with caution because of the different sample sizes and effect sizes presented during the statistical analysis. The statistical analysis (reporting Hedges' g score) of the quantitative data concluded variations in effect size between the quantitative studies, as well as variations of samples between the studies. This and the effectiveness variations between the two groups reported in the results section suggest concern about the validity and generalisability of computer-aided nursing pedagogies.

On the other hand, this SLR contradicts the conclusions of [17] that mobile applications increase nursing students' satisfaction but do not contribute to knowledge gains. Most mobile applications in this SLR were found superior to traditional nursing educational methods regarding knowledge gains. The differences between the two findings could be because this SLR included more innovative mobile application technologies, such as AR-enabled mobile applications, as opposed to [17]. Therefore, it might be speculated that nursing students' increased engagement contributes to improved knowledge outcomes, as new technology typically attracts more attention [72].

D. RESEARCH QUESTION 3

This SLR concluded overall positive experiences of student nurses exposed to computer-aided nursing education pedagogies. As mentioned above, exposure to new technology may be a reason for the positive experiences of nursing students [138]. However, some student nurses exposed to computer-based nursing education pedagogies were distracted from learning activities. As recommended by [2], when implementing innovative pedagogical methods in nursing education, the technology should not distract learners but engage them in learning activities [2].

However, on the other hand, most of today's nursing students are so-called "Generation Z" (which is closely related to technology development). Therefore, to gauge their attention, technology should be implemented in nursing education [66]. Nevertheless, more research is needed to investigate if technology in education distracts nursing students from long-term knowledge gains or contributes to better learning experiences. Another finding associated with negative nursing experiences is the "immersive sickness" occurring when nursing students wear a VR headset, which might be able to be prevented by implementing the most advanced hardware technology, as proven by [120]. On the other hand, this is associated with higher expenses, which many universities might not be able to comprehend.

In addition, some nursing students reported ethical concerns about using AI in education (AIED) and chatbots. Similarly, the literature acknowledges some ethical issues concerning chatbots, specifically the Chat Generative Pre-Trained Transformer (ChatGPT) created by Open AI [139]. ChatGPT is a chatbot using NLP that could be helpful in education due to its instant feedback and extensive knowledge base. According to [140], ChatGPT can be a virtual patient and help nursing students communicate more effectively and improve their confidence and knowledge. Also, a variety of clinical scenarios can be accessed through this AI application. The authors tested the ChatGPT's accuracy in answering the "National Council Licensure Examination-Registered Nurse" (NCLEX-RN) questions, which resulted in correct results. However, the authors recognise the possibility of algorithmic errors and, therefore, false information provided to nursing students.

Furthermore, as noted by [141], ChatGPT needs more access to databases in nursing, which might indicate poor reliability regarding theoretical knowledge in nursing education and plagiarism issues [142]. ChatGPT could be very beneficial, but the challenge is teaching nursing students to use it ethically, such as help with finding materials, etc. Another ethical issue arising from ChatGPT or the team behind ChatGPT is naming them as an author in a publication, which raises concerns in the academic world [142]. However, [142] accepts the benefits of ChatGPT but calls for clear guidance to secure the ethical use of such innovative technologies. It is worth mentioning that many institutions have banned their nursing student from using it due to plagiarism issues [142]. Some authors noted that for the universal deployment of AI technology, standard implementation, well-developed infrastructure and universal frameworks must be established first [143].

Finally, this SLR acknowledges that the feelings of frustration reported by nursing students in this SLR are mainly due to technical issues (poor Wi-Fi connection, phone incompatibility with a system, the weight of some equipment, etc.). In addition, nursing students highly requested to provide more realistic scenarios and computerised images despite the various designing platforms and techniques used by the authors included in this SLR. Therefore, with the digital transformation and recent advances in AI in education, machine vision technology [144], deep learning techniques and algorithms already used in other domains [145] could be the solution for enhancing nursing students' learning experiences [146]. However, as mentioned above, the cost of advanced technology implementation in nursing education should be considered.

VIII. LIMITATION AND FUTURE RECOMMENDATIONS

Despite the authors' attempt to gather robust evidence, this SLR has few limitations.

To begin with, the generalisability of the findings might be compromised, as all articles were published in 20 developed countries, with variations in technology development, economic status, nursing educational systems, and culture, which this SLR discussed but did not explore thoroughly. As this SLR did not identify any articles from developing countries eligible for inclusion, the authors recommend further investigation into computer-aided nursing education pedagogies in developing countries or countries with low economic status. In addition, the credibility and reliability of the findings might be compromised due to the variations in sample size and effect size among the articles examining effectiveness. In addition, the timeline of included articles was 2013-2023. However, more studies might be published by the end of 2023, which this SLR will not include. Therefore, the authors recommend future researchers to focus on identifying more emerging nursing pedagogies, such as the role of Metaverse, Robotics, smart clothing, etc. Moreover, future researchers should focus on pedagogies to examine the affective component in nursing computer-aided educational systems. In addition, underinvestigated nursing pedagogies, such as the Intelligent Tutoring system (ITS) in nursing education, should be further studied. In addition, longitudinal studies should be conducted in the future to examine nursing students' knowledge retention when exposed to computer-aided nursing pedagogies. Most of the scenario-based pedagogies in this SLR followed pre-defined scenarios. However, some of the included studies reported nursing students' desire for more memorable and realistic scenarios in nursing students' satisfaction and knowledge gains. Therefore, future researchers might examine nursing students' experiences and knowledge gains when exposed to computerised systems that can utilise scenarios with unexpected outcomes.

IX. CONCLUSION

This mixed methods SLR examined a total of 78 articles from 20 different countries published before, during and post-COVID-19 Pandemic (2013-2023). The findings presented an increasing trend of published articles about computer-aided nursing pedagogies before, during and after the COVID-19 pandemic. The variety of computer-based systems in nursing education was evident, with overall superiority to traditional nursing pedagogies regarding knowledge and skills acquisition, self-efficiency, and nursing students' experiences and attitudes. However, this outcome should be interpreted cautiously due to variations in sample size and effect size established via individual *t*-tests and Hedges' g score among the 35 quantitative articles. In addition, it is not clear if these findings could be generalisable in nursing education in low socioeconomic factors and developing countries. Therefore, larger samples with diverse sociodemographic characteristics are required to confirm the generalisability of the findings in future studies.

Official bodies have recognised the importance of upgrading nursing education pedagogies, and some actions have already been taken. However, research is still being conducted regarding investigating innovative nursing educational methods. Although there are attempts to implement innovative technologies, such as AI's use in nursing education, the research conducted to test their efficiency and feasibility needs to be improved. Smartphones are preferred over computers for designing computerised systems in nursing education. Student engagement and learner satisfaction were generally high. However, proper frameworks and scales dedicated to examining efficiency in nursing education are needed. Future research directions should explore computer-aided pedagogies in developing countries and countries with low socioeconomic factors. In addition, investigating long-term knowledge gains in nursing students exposed to computer-aided nursing pedagogies, as well as investigating the affective domain in nursing education, should be prioritised by future researchers. Moreover, conducting more RCTs with larger sample sizes will lead to more evidence-based conclusions about computer-aided nursing pedagogies' effectiveness. This SLR risks a selection bias due to the specific exclusion criteria applied for the articles' searchers. Further research should examine nursing lecturers' opinions.

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