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Review

Quality and impact of pharmacology digital simulation education on pre-registration healthcare students: A systematic literature review

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ABSTRACT

Objective: This review aimed to assess the quality and nature of the literature related to digital simulation-based pharmacology education. Specifically, we sought to understand the influence of simulations on the knowledge, satisfaction, and confidence of pre-registration nurses and other healthcare students participating in such educational programs.
Design: Systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement. This study was registered in the Prospective Register of Systematic Reviews (PROSPERO, reg no: CRD42023437570).
Data sources: PubMed, MEDLINE, APA PsycInfo, ProQuest, Web of Science, ScienceDirect, and CINHAL databases were searched.
Review methods: The review focused on the quantitative findings from the studies published from 2016 to 2023. Only the studies that assessed the impact of digital simulation-based pharmacology education on pre-registration healthcare students' knowledge, satisfaction, and confidence were selected for review. Data were synthesized using a narrative approach. The Mixed Methods Appraisal Tool (MMAT) was used to assess the quality of the included articles. This was followed by a narrative synthesis to consolidate the themes.
Result: Out of 1587 articles,16 met the inclusion criteria. A wide variety of digital technologies have been utilised, such as virtual simulation, computer simulation (2D/3D), mixed reality, and augmented reality, with the majority using virtual simulation. All studies implemented single-user simulations. The themes emerging from the narrative synthesis suggest that a digital simulation-based pharmacology course is an effective tool for enhancing students' knowledge, confidence, and satisfaction in learning pharmacological concepts. Furthermore, simulation-based teaching with a blended approach was found to be beneficial. However, the integration of the polypharmacy concept and the intra and interprofessional approach to teaching and learning was not evident in these studies.
Conclusion: This systematic literature review provides evidence of the potential of digital simulation-based education in pharmacology teaching among healthcare pre-registration students. In future studies, the integration of polypharmacy content with an intra and interprofessional teaching-learning approach is recommended.

1. Introduction

Globally, medicine-related harm is a patient safety and quality of care issue (Assiri et al., 2018). Drug prescription and administration errors can result in increased morbidity and mortality(Naples et al., 2016; Roughead et al., 2016). As the healthcare system increasingly moves towards being delivered in the community and integrated health and social care settings, medicine optimisation and the prevention of medicine-related harm are fundamental requirements for future care delivery (Anderson and Sharma, 2020; British Medical Association [BMA] and National Health Services [NHS], 2019). Prescriptions written by non-medical professionals (NMPs), such as prescribing nurses, midwives, and pharmacists, are legal in the majority of countries reflecting broad interprofessional prescribing collaboration in healthcare(Ecker et al., 2020). Moreover, it highlights the importance of equipping healthcare professionals with the necessary knowledge and skills to reduce medicine-related harm by optimising safe prescriptions and medicine management (Hanson and Haddad, 2022; NHS, 2023).

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Despite this patient safety concern, studies show that a lack of pharmacological expertise, knowledge, confidence in clinical decision-making, and critical thinking are factors associated with medication errors (Escrivá Gracia et al., 2019; Kumar, 2015; Mertens et al., 2023). This suggests enhancements of pharmacological knowledge, prescribing, and medicines optimisation among healthcare pre-registration students are needed. Pre-registration health care students in the study refer to nursing, medical, pharmacy, and allied health students who are in the process of gaining essential competence and proficiency prior to full licensure or registration for independent practice in their respective discipline. In addition, prescribing curricula are well-established in healthcare education fields such as medicine, nursing, and pharmacy (Fens et al., 2020). In the UK, nursing has one of the most liberal prescribing legislation in the Western world with preparation for prescribing from a limited formulary permitted at the point of registration (Gielen et al., 2014; Kroezen et al., 2011). Therefore, exploring a systematic teaching-learning approach to enrich students' knowledge and clinical reasoning in medicines optimisation is essential.

There is growing evidence of the significant contribution that simulated practice learning has made to healthcare education, and it has received professional and policy endorsement in the UK(Harison et al., 2024; Kononowicz et al., 2019). This represents a shift towards more interactive and immersive educational approaches (Kononowicz et al., 2019; Lall et al., 2019). Digital simulation has been demonstrated as an effective pedagogy that supports student learning outcomes (Kononowicz et al., 2019). The current Nursing and Midwifery (NMC) standard highlights the importance of incorporating technology and simulation in nursing education to improve learning, create immersive experiences, and better prepare students for their careers (NMC, 2023). It is purported that preparing healthcare students using simulated practice learning will equip them with the necessary skills and competencies to reduce medicines-related harm in practice.

Literature suggests that student performance and knowledge are linked to satisfaction and confidence. For example, studies have evaluated the correlation among healthcare students' knowledge, satisfaction, and confidence in a simulated learning context with a mixed picture of success (Kononowicz et al., 2019; Mann and Obisesan, 2022; Meyer et al., 2017; Yang et al., 2023). Several studies have explored the various forms of simulation-based pharmacology courses and their effectiveness (Andrews and Barta, 2020; Meyer et al., 2017). However, only a few studies have reported objective measures of digital simulation-based pharmacology learning in pre-registration healthcare students (Ezeala, 2020; Smith and Davis, 2021; Yang et al., 2023). Therefore, the primary objective of this review is to systematically review the range of digital simulation-based pharmacology courses available in pre-registration healthcare education programs and their impact on knowledge, satisfaction, and confidence. This will inform future research and the design of evidence-based healthcare curricula.

2. Methods

2.1. Aims

The aims of the review were as follows:

1. To identify the formats of digital simulation-based pharmacological interventions among healthcare pre-registration students worldwide.
2. To identify the impact of digital simulation-based pharmacology interventions on knowledge, satisfaction, and confidence among healthcare pre-registration students.
3. To assess the quality of evidence.
4. Identify gaps in the literature to inform the direction of future research and education.

2.2. Design

A rigorous and empirically determined solution to the research question was produced using a systematic review in the narrative technique, which helped to synthesise and evaluate all relevant articles (Popay et al., 2006). A systematic review was chosen for this literature review to detect gaps in the body of information, the strength of the evidence base, the synthesis of findings, and the provision of crucial insights for directing and enhancing practices(Gopalakrishnan and Ganeshkumar, 2013; Pryce-Miller, 2015). The reporting of this systematic review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement(Page et al., 2021).

2.3. Preliminary search and keywords

A preliminary search was carried out using Clinicatrial.gov, Prospero, PubMed, and Google Scholar to ensure the validity of the proposed idea, avoid duplication of previously addressed questions, and ensure that the author had sufficient articles to conduct the analysis. We found no systematic reviews or meta-analyses on this topic. This study was registered in the Prospective Register of Systematic Reviews (PROSPERO, reg no: CRD42023437570) before the research was carried out.

The criteria for selecting keywords associated with Medical Subject Headings (MeSH) terms were applied appropriately to develop an advanced search and retrieve the articles most relevant to the research question. The search process of the databases used the combination of the main terms 'Simulation,' 'pharmacology/prescribing/medicine administration,' and 'students.' The combined Boolean operators 'AND' and 'OR' were used in specific ways to broaden or narrow the results, as illustrated in Table 1.

2.4. Eligibility criteria

The studies were selected drawing on elements of the broad **P**opulation - **I**ntervention - **C**omparison – **O**utcome (PICO) framework recommended by Santos et al. (2007). The comparison element was implicit throughout the examination. The inclusion criteria for this systematic review are summarised in Table 2 and focused on pre-registration healthcare students, excluding practicing and registered healthcare professionals and post-registration healthcare students. Studies that included digital simulation-based pharmacology as an intervention are included in the review. All studies that reported the impact of such interventions on knowledge, confidence, and satisfaction were included. The quantitative findings from the primary research studies with quantitative and mixed-method designs were reported in the review. Only studies published in the English language between 2016 and 2023 were included.

Table 1
List of keywords and data sources.

List of keywords			
Intervention		Population	Outcome
VR OR Digital Simulation OR Computer-based simulation OR Virtual simulation OR Virtual Reality OR Augmented reality OR Mixed reality OR AR	Pharmacology OR Prescribing OR medicine administration OR medication administration OR medication error OR adverse drug event	Students OR University OR study* OR teach*	knowledge OR learn* OR educat* OR understanding OR satisfaction OR confidence OR perception OR experience

Table 2
Inclusion and exclusion criteria.

Parameter	Inclusion criteria	Exclusion criteria
P (Population)	Pre-registration healthcare students: - medical, nursing, pharmacy, physiotherapy, therapeutic radiographer, optometry, and podiatry.	Practicing health care professionals Post-registration healthcare students Registered healthcare professionals
I (Intervention)	Pharmacology education (as a whole or combined with other teaching material) based on • Digital simulation • Virtual simulation • Virtual reality • Augmented reality • Mixed reality • Computer simulation	Manikin /Mannequin based simulation. Simulation involving human/animal participants to deliver the intervention. Simulation training is done for purposes other than teaching pharmacology content. Coaching method Online training Workshops
O (Outcomes)	Measures on • Knowledge • Confidence • Satisfaction	Studies that have not measured outcomes based on pharmacology concepts. Studies that have outcomes excluding knowledge, confidence, and satisfaction.
Study design	Primary research with • Quantitative design, • Mixed method design (only quantitative findings extracted).	Design: Qualitative design, qualitative findings of the mixed method studies. Reviews: - meta-analysis, systematic literature review, and scoping review. Grey literature; press releases, blog posts, case reports, conference papers, and unpublished manuscripts.
Scope	Language: English Full text Dates: 2016–2023	Language: Other than English Abstract only Dates: 2015 and older.

2.5. Search strategy

The search was conducted by a lead researcher (SR) in March 2023. The following databases were searched: PubMed, MEDLINE, ProQuest, Web of Science, APA PsycInfo, ScienceDirect, and CINHAL. Additionally, a manual search was conducted using citation lists, relevant journal index lists, registries, publications from scientific meetings, and relevant conferences. The data sources and search strategy are presented in supplementary files A and B, respectively.

2.6. Selection process

The search was restricted to primary research articles published in English between 2016 and 2023. All records were imported using Mendeley Reference Manager. The selection process followed the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines(Page et al., 2021). This included three main stages (identification, screening, and selection) following the inclusion and exclusion criteria:

- Identification of studies via databases, registers, websites, and citation searching
- Screening done by removing duplicate articles.
- Reviewing further for the title and the abstract. Followed by reviewing the full text based on the PICO and inclusion criteria.

The extracted papers were discussed and reviewed by a peer (GG) to process for data extraction. Any disagreements between the peer reviewers were resolved through a comprehensive discussion by referring to the critical appraisal tool and with supervisors (RP and AM).

2.7. Data items

All the primary studies that have utilised any form of digital simulation-based pharmacology course were included as one data set to address the first objective of the review. Furthermore, the outcomes mentioned in the eligibility criteria were considered for data. The outcome data relating to only medicine administration and medication dispensing skills were excluded as this review aims to see the impact of such courses on knowledge, satisfaction, and confidence. There was no limitation to the geographical orientation of the study. However, the study was only limited to the pre-registration healthcare students.

2.8. Result synthesis

From the nature of search results against eligibility criteria, diverse forms of interventions were used across the studies, such as different types of quantitative research designs and a variety of outcome measures. Therefore, the narrative synthesis approach was applied as defined by Popay et al. (2006).

2.9. Quality appraisal

To appraise the range of evidence reported, the Mixed Methods Appraisal Tool (MMAT) was used to assess the quality of potential papers(Hong et al., 2018). The MMAT is a valid and reliable tool that allows a detailed presentation of the ratings of each section of the study and permits a methodological appraisal of the studies. The quality of the papers was assessed based on five study designs following the MMAT checklist. The identified studies were systematically charted in tabular form to align with the study objectives and study characteristics. Table 3 presents the results of data extraction and quality appraisal of studies.

3. Results

All identified studies from databases, websites, and search engines

Table 3
Data extraction.

SN	Author/Place	Aims/ Objective	Population/ sampling strategy	Design	Intervention/ Measure	Instrumentation used/ Data analysis	Results	Overall MMAT rating
1	(Abdel Haleem et al., 2023) Saudi Arabia	To explore the utilization of computer-based simulation in the field of pharmacology experiments in medical education.	**Population** Undergraduate medical students **Sampling method** Convenient sampling **Sample size** 60	**Quantitative descriptive study**	**Experimental group** Virtual computer simulation (Pharmacology virtual laboratory simulation software) **Control group** N/A **Measure** Students' reactions (at the Kirkpatrick level	Self-designed questionnaire. **Data analysis** Descriptive statistics	**General perception of knowledge** 48.3 % rated the practical enforcement of theoretical knowledge as good, 38 % percent appreciated the learning experience. **Application use** 75 % of males reported that the handling of the tool was simple, with the provision of an excellent learning experience of 80 %.	**Strong**
2	(Chan et al., 2021) Taiwan	To apply a Virtual Reality(VR) education program to improve the knowledge and attitude of the undergraduate students exposed to cytotoxic drugs and to assess the effect of the VR education program on the knowledge and practice of these students.	**Population** Undergraduate nursing students **Sampling method** Random sampling **Sample size** 77	**Randomized control trial**	**Experimental group** Virtual reality simulation (chemotherapy administration) **Control group** Educational documents **Measures** Knowledge and satisfaction.	Knowledge: Self-designed and validated. Satisfaction: Self-designed and validated. **Data analysis** Descriptive and inferential analysis Analysis of variance (ANOVA)	**Knowledge** The knowledge of the students was significantly increased in experimental compared with those who read the document (7.10 ± 1.41 vs. 6.12 ± 1.38, $p = 0.013$) **Satisfaction** The experimental group was more satisfied with the results than those in the control group (*P* value = N/A)	**Strong**
3	(Dubovi et al., 2018) Israel	To evaluate the effectiveness of multiscale agent-based computer models for complex-systems levels of thinking to support nursing students' learning of pharmacology simple rules.	**Population** Sophomore nursing student **Sampling method** Convenience Sampling **Sample size** 148	**A quasi-experimental pre-and post-test design**	**Experimental group** Computer-based simulation (Pharmacology PILL-Cells Environment) **Control group** Lecture-based course **Measure** Knowledge	**Knowledge** Self-designed and validated. **Data analysis** Descriptive statistics (Mean, SD) Mann–Whitney *U* test ANOVA	**Knowledge** Conceptual learning was significantly higher for the experimental than for the control group for the course final exam scores (unpaired $t = -3.8$, $p < 0.001$) and for the Pharmacology-Diabetes-Mellitus questionnaire ($U = 942$, $p < 0.001$).	**Strong**
4	(Giordano et al., 2020) USA	Pilot the use of a virtual reality simulation for training student nurses to identify signs and symptoms of an OOD, properly administer intranasal naloxone, and provide immediate recovery care after revival.	**Population** Undergraduate nursing students **Sampling method** Random sampling **Sample size** 50	**Quasi-experimental pre-test post-test study**	**Experimental group** VR simulation for Opioid overdose management and naloxone administration. **Control group** Hybrid simulation **Measure** Knowledge	Knowledge: Opioid Overdose Knowledge Scale (OOKS) **Data analysis** Descriptive statistics t-test chi-square Shapiro-Wilk test	**Knowledge** There was no statistically significant difference in the mean OOKS score change from baseline to follow-up, both within the whole sample (−0.38 ± 0.51)($P = 0.229$), as well as across control group (−0.26 ± 3.01) and experimental groups (−0.58 ± 1.64).	**Strong**
5	(Hanson et al., 2019) Australia	To measure the (a) effectiveness, (b) level of discomfort such as headache, dizziness or motion sickness, and, (c) student perceptions of satisfaction of using a 3D artefact in CAVE2™	**Population** Undergraduate nursing and midwifery students **Sampling method** Random	**Mixed methodology (pre- and post-test)**	**Experimental group** CAVE2™ 3D visualisation simulation (Drug-receptor binding of a β-adrenoceptor)	Knowledge acquisition: (self-designed questionnaire) **Satisfaction** (Modified	**Knowledge acquisition** Student scores significantly improved for students in both the experiment and control groups, but	**Strong**

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Table 3 (*continued*)

SN	Author/Place	Aims/ Objective	Population/ sampling strategy	Design	Intervention/ Measure	Instrumentation used/ Data analysis	Results	Overall MMAT rating
		on undergraduate nursing and midwifery students' pharmacodynamic knowledge of drug-receptor binding compared to exposure using a two-dimensional (2D) wide screen.	sampling **Sample size** 202		**Control group** 2D visualisation wide screen **Measures** Knowledge acquisition Satisfaction	Satisfaction with Simulation Experience Scale) (SSES-M) **Data analysis** Mcnemars test Standard deviation Paired t-test	the experimental group had a significantly greater improvement (1.16 vs. 0.55 out of 5; $P = 0.013$; 95 % CI for the difference from 0.30 to 1.10 higher for the experimental group; $P = 0.0013$). **Satisfaction** Students were generally satisfied with both immersion techniques, and scores for the 3D immersion were higher for each subscale, but not statistically significant.	
6	(Hanson et al., 2020) Australia	To compare the effect on student learning, satisfaction and comfort following exposure to a 3D pharmacology artefact in a virtual facility (CAVE2) with viewing of the same artefact using a mobile handled device with stereoscopic lenses attached.	**Population** Undergraduate nursing and midwifery students **Sampling method** Convenience sampling **Sample size** 249	**Mixed method (Pre-test post design)**	**Experimental group** 3D artefact, CAVE2™ immersion learning experience (Immersive virtual reality) of a pharmacological concept (drug-receptor binding of aβ-adrenoceptor) **Control group** 3D artefact with handheld mobile device. (stereoscopic lenses attached) **Measures** Knowledge acquisition Satisfaction scores	Knowledge acquisition: (self-designed questionnaire) Satisfaction: (Modified Satisfaction with Simulation Experience Scale (SSES-M) **Data analysis** t-test Fisher exact test	**Knowledge acquisition** The mean increase in scores was statistically significant for both methods ($P < 0.001$). **Satisfaction** There was no difference in student satisfaction for the reflection sub-scale for both methods, but the average student satisfaction for clinical reasoning ($P = 0.013$)and clinical learning ($P < 0.003$) with the experimental was higher than the control group. There was no significant difference in satisfaction with debriefing and reflective practice processes($p = 0.377$) in both groups.	**Strong**
7	(Pence, 2022) USA	To evaluate the impact of vSIM on satisfaction and self-confidence.	**Population** Accelerated Bachelor of Science in nursing students **Sampling method** Convenience sampling g **Sample size** $N = 28$	**Descriptive mixed method study**	**Experimental group** vSim for pharmacology **Control group** N/A **Measures** Satisfaction Self-confidence	Satisfaction and Self-confidence: (NLN Student Satisfaction and Self-Confidence in Learning Questionnaire) **Data analysis** Percentage and standard deviation	**Self confidence** 43 % - agreed /strongly agreed they were confident in mastery of content during vSims. 46 % - were confident in developing skills and knowledge from vSims to perform tasks in a clinical setting. 36 % - were confident vSims covered critical content necessary for mastery of the pharmacology curriculum. **Satisfaction** 50 % of participants agreed vSims were helpful and an effective strategy. 54	**Strong**

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Table 3 (*continued*)

SN	Author/Place	Aims/ Objective	Population/ sampling strategy	Design	Intervention/ Measure	Instrumentation used/ Data analysis	Results	Overall MMAT rating
							% agreed/strongly agreed vSims provided a variety of materials and activities to promote learning pharmacology.	
8	(Persoulla et al., 2020) Cyprus	To explore the impact of introducing VP-based tutorials to supplement traditional teaching in medical pharmacology course taught in pre-clinical years.	**Population** 3rd year undergraduate medical students **Sampling method** N/A **Sample size** Total ($n = 75$) Cohort 1 ($n = 31$) Cohort 2 ($n = 44$)	**Naturalistic Prospective study**	**Cohort 1 and 2 intervention** Case-based discussion (CBD), single best answer questions (SBAs) —Midterm — Virtual patient tutorial— final term **Experimental measure** Student performance, satisfaction, and perception after the final exam (cohorts 1&2) **Control measure.** Student performance, satisfaction, and perception after midterm (cohort 1) **Measures** Performance in examination, Satisfaction and perception	Performance in examination Satisfaction and perception (validated modified questionnaire) **Data analysis** t-test linear regression analysis	**Performance** Cohort 1 students performed significantly better in the final examination ($P = 0.04$]), Students in cohorts 1 and 2 performed significantly better in the final examination on assessment items related to teaching in the virtual patient (VP)-based tutorials, compared with a single-best-answer question and case-based discussion (SBA/CBD)-based tutorial ($p = 0.04$) **Student Satisfaction and Perceptions** Acquisition and maintenance of knowledge: Both types of tutorials were perceived to be effective in facilitating the acquisition and maintenance of pharmacological knowledge. control: 4.45 (SD 0.46); VPs: 4.46 (SD 0.50) Facilitation of learning: VP-based tutorials were perceived to facilitate their learning to a greater extent compared with the CBD/SBA tutorials. [control: 3.49 (SD 0.76); VPs: 3.87 (SD 0.70); P = 0.01 .Inauthenticity of learning: Students rated both types of tutorials favorably in terms of the authenticity of learning and representation of cases control: 1.67 (SD 0.67); VPs: 1.63 (SD 0.61). Disadvantages of learning: Students did not perceive either type of tutorial to be disadvantageous to their learning control: 1.53 (SD 0.54); VPs: 1.59 (SD 0.59).	**Strong**
9	(P et al., 2018) India	To study the effectiveness of	**Population** 2nd-year	A cross-sectional	**Experimental group**	Knowledge Multiple choice	**Knowledge** The students had a	**Moderate**

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Table 3 (*continued*)

SN	Author/Place	Aims/ Objective	Population/ sampling strategy	Design	Intervention/ Measure	Instrumentation used/ Data analysis	Results	Overall MMAT rating
		computer-assisted learning (CAL) by comparing demonstration methods using live animals and CAL methods among 2nd year MBBS students.	medical students **Sampling method** N/A **Sample size** 71	questionnaire-based observational study	Interactive Computer assisted learning (CAL) {effect of diazepam on mice} **Control group** Demonstration of the experiment using live animals. **Measures** Knowledge	questionnaire and feedback questionnaire (validated) **Data analysis** Frequency analysis	better average score in CAL method as compared to the method using animals (82.4 % vs. 44.6 %). Based on feedback, the majority of students (70 %) agreed in favor of CAL.	
10	(Saastamoinen et al., 2022) Finland	To explore the competence of the medication administration process before and after the 3D simulation To explore the difference between intervention and control group medication administration management.	**Population** Undergraduate Nursing students **Sampling method** Simple random sampling **Sample size** 123	**Quasi-experimental design (pre/ post-test)**	**Experimental group** IMAGINE (Interactive Medication Administration Game Intervention for Nurses Education) 3D simulation game, a 2-h game. **Control group** Online learning material **Measures** Knowledge	Knowledge questionnaire (self-designed) **Data analysis** Mann-Whitney U test Descriptive statistics	**Knowledge** Theoretical knowledge before/ after intervention **Before Intervention:** Experiment: 84.4 % ($n = 60$), Control: 83.5 % ($n = 43$) **After Intervention**: Experiment: 94.2 % ($n = 67$) Control: 96 % ($n = 50$) Both interventions were equally good. Theoretical knowledge increased in both groups in those statements where it had been weak e.g., pharmacology.	**Strong**
11	(Schneider et al., 2020) Australia	To develop an AR tool and investigate its effectiveness for learning about the medication naloxone using AR in a Magic Book To determine student opinions on its acceptability and usability.	**Population** Undergraduate pharmacy students **Sampling method** Convenience sampling **Sample size** 25	**Sequential explanatory, mixed method design**	**Experimental group** AR Magicbook (based on HP Reveal ® AR platform) AR trigger images, videos, audio or 3D models, which are immediately available and can be visualised using the camera of any mobile device. **Control group** N/A **Measures** Knowledge	Knowledge questionnaire (self-designed) **Data analysis** Two-tailed Paired t-test	**Knowledge** AR technology was able to support student learning on the chosen topic, showing a 42 % improvement in quiz scores $p < 0.0001$, total pre-and post-test scores ($t = 7.45$, $p < 0.001$, sd = 1.42, df = 24).	**Strong**
12	(Tiwari et al., 2019) India	To evaluate the performance of students on conventional teaching methods (such as lecture and demonstration) followed by CAL experiments on the same topics of experimental pharmacology.	**Population** Undergraduate medical students **Sampling method** N/A **Sample size** 109	**Non randomized study**	**Experimental group** Computer-assisted learning software (CAL) (An interactive computer-assisted learning) **Control group** N/A **Measures** Students performance	Knowledge questionnaire (self-designed) **Data analysis** Descriptive statistics	**Knowledge** A statistically significant difference ($p < 0.05$) in the performance was observed among the students in the pre-CAL and post-CAL assessments, with higher in the post-CAL group.	**Strong**
13	(Turrise et al., 2020) USA	To investigate the effectiveness of Digital Clinical Experience (DCE) in improving critical thinking in accelerated online RN-BSN students enrolled in a pathophysiology-pharmacology class and to determine student satisfaction and confidence using DCEs	**Population** Nursing students **Sampling method** Convenience sampling **Sample size** 27	**Randomized control pretest post-test design**	**Experimental group:** Digital Clinical Experience (DCE) in the form of 3 different patient scenario basis **Control group:** Learning with Case studies of 3 different patient scenarios	Satisfaction and confidence: Student Satisfaction and Self-Confidence in Learning Tool **Data analysis** Descriptive study One-way repeated-measure ANOVA	**Satisfaction and confidence** Participants in experimental group had higher confidence and satisfaction in learning compared with control (M = 35.61, SD = 4.35 vs. M = 33.86,vs. SD = 3.99), and (M = 22.46, SD = 2.82 vs.	**Strong**

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Table 3 (*continued*)

SN	Author/Place	Aims/ Objective	Population/ sampling strategy	Design	Intervention/ Measure	Instrumentation used/ Data analysis	Results	Overall MMAT rating
					Measures Satisfaction and confidence		M = 20.7, SD = 3.68), respectively. However, there was no statistical significance between groups: satisfaction ($p = 0.199$) and confidence in learning ($p = 0.284$).	
14	(Veer et al., 2022) Australia	To assess the effectiveness of a textbook style or a three-dimensional mixed reality (MR, a hybrid of augmented and virtual reality) HoloLens resource for student learning and knowledge retention using asthma as a model of disease.	**Population** 1st year Undergraduate medical students, and health science. **Sampling method** Convenience sampling **Sample size** 67	**Randomized control trial**	**Experimental group** Mixed reality (Asthma and a model of disease) **Control group** Textbook-style written (TB) resource group. **Measures** Knowledge	Knowledge questionnaire: (self-designed and validated) **Data analysis** Student-paired one-tailed t-test Mann Whitney U test Student's two-tailed unpaired t-test one-way analysis of covariance (ANCOVA)	**Knowledge test** scores Participants in the textbook-style group obtained higher post-test scores (/15) than the mixed reality group [Textbook- (p = 0.001) vs MR - $p = 0.05$)]. **Knowledge retention** after 2 weeks overall scores reduced by 1.73 for the textbook-style group and 0.9 for the mixed reality group. However, no significant difference.	**Strong**
15	(Zaragoza-García et al., 2021) Spain	To evaluate if the web-based virtual simulation platform is a useful tool in terms of knowledge, satisfaction, and self-confidence.	**Population** Last year undergraduate nursing students **Sampling method** N/A **Sample size** 51	**A quasi-experimental study**	**Experiment group** Scenario-based virtual simulation (VS) training **Control group** In-person practical training **Measures** Knowledge Confidence satisfaction	Knowledge questionnaire: (Self-designed and validated) Satisfaction and confidence: Student Satisfaction and Self-Confidence in Learning Tool **Data analysis** Fisher's or Chi-squared test Wilcoxon test Mann-Whitney U test	**Knowledge** In the experimental group, a significant increase in knowledge after intervention (median = 5.6 vs. 9.4; $p < 0.001$) Knowledge improvement in the experimental group was also significant compared to the control group (median = 9.4 vs. 5.0; $p < 0.001$) **Satisfaction and confidence** Students showed high levels of satisfaction and self-confidence with the training received indicating a median score. (> 4/5 points).	**Strong**
16	A Scenario-Based Virtual Patient Program to Support Substance Misuse Education (Zlotos et al., 2016) UK	To evaluate virtual patient (VP) programs for injecting equipment provision (IEP) and opiate substitution therapy (OST) services with respect to confidence and knowledge among pre-registration pharmacist trainees.	**Population** Pre-registration trainee pharmacist **Sampling method** N/A **Sample size** 106	**Before and after Experimental study**	**Experimental group** Virtual patient scenario injecting equipment provision (IEP) and opiate substitution therapy (OST) provided as a part of the curriculum. **Control group** N/A **Measures** Knowledge Confidence	Knowledge questionnaire: Self-designed Confidence Self-designed **Data analysis** Wilcoxon test Friedman's pairwise comparison McNemars and Bi-nomial	**Knowledge** Significant improvement between pre-scores and postscores for IEP ($Z = 5.8, p < 0.001$) and OST ($Z = 5.9, p < 0.001$) This was also true for the pre-program and 6-month scores for IEP($Z = 2.6, p < 0.017$) and OST ($Z = 4.8, p < 0.001$) Significant decrease in scores between the post-test and 6-month test scores for both scenarios (IEP, $Z = 5.50, p < 0.001$: OST, $Z = 5.8, p < 0.001$).	**Strong**

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Table 3 (*continued*)

SN	Author/Place	Aims/ Objective	Population/ sampling strategy	Design	Intervention/ Measure	Instrumentation used/ Data analysis	Results	Overall MMAT rating
							Confidence confidence was significantly greater than pretest confidence compared to just after and in six months time (Wilcoxon signed rank test, $p < 0.0001$, $p < 0.01$ and $p < 0.05$ respectively)	

were exported to the Mendeley reference manager software. A total of 1571 articles were obtained from seven databases: six from websites/ Google Scholar/Edinburgh Napier Library searches, two from organisations, and eight from citation searches. Articles identified in the database were screened for duplicate records, and 464 articles were removed. Subsequently, the remaining articles were screened and excluded based on title, abstract, inclusion and exclusion criteria, and study context. The final outcome of screening yielded 16 studies that met the inclusion and exclusion criteria based on the literature review objectives. The detailed study selection process is illustrated in the PRISMA flowchart in Fig. 1. Geographical spread was as follows: three studies were conducted in the USA(Giordano et al., 2020; Pence, 2022; Turrise et al., 2020), four in Australia(Hanson et al., 2019, 2020; Schneider et al., 2020; Veer et al., 2022), four in Europe(Persoulla et al., 2020; Saastamoinen et al., 2022; Zaragoza-García et al., 2021; Zlotos et al., 2016), and five in Asia(Abdel Haleem et al., 2023; Chan et al., 2021; Dubovi et al., 2018; P et al., 2018; Tiwari et al., 2019).

The total number of participants across the studies was $n = 1468$ (range 25–249). Healthcare student participants were nurses (70 %, $n = 1027$), medical students (21 %, $n = 308$), and pharmacy students (9 %, $n = 133$).

3.1. *Quality of research*

The details of the critical appraisal are presented in Table 3. The appraisal yielded scores ranging from moderate to strong. Five were randomized control trials (RCT)(Chan et al., 2021; Giordano et al., 2020; Saastamoinen et al., 2022; Turrise et al., 2020; Veer et al., 2022), five were quantitative non-randomized trials(Dubovi et al., 2018; Persoulla et al., 2020; Tiwari et al., 2019; Zaragoza-García et al., 2021; Zlotos et al., 2016), two were quantitative descriptive studies (Abdel Haleem et al., 2023; P et al., 2018), and four were mixed-method studies(Hanson et al., 2019, 2020; Pence, 2022; Schneider et al., 2020).

For knowledge measures, five studies used validated tools (Chan et al., 2021; Dubovi et al., 2018; Giordano et al., 2020; Veer et al., 2022; Zaragoza-García et al., 2021), and nine studies used self-designed tools without discussing their validity (Abdel Haleem et al., 2023; Hanson et al., 2019, 2020; P et al., 2018; Persoulla et al., 2020; Saastamoinen

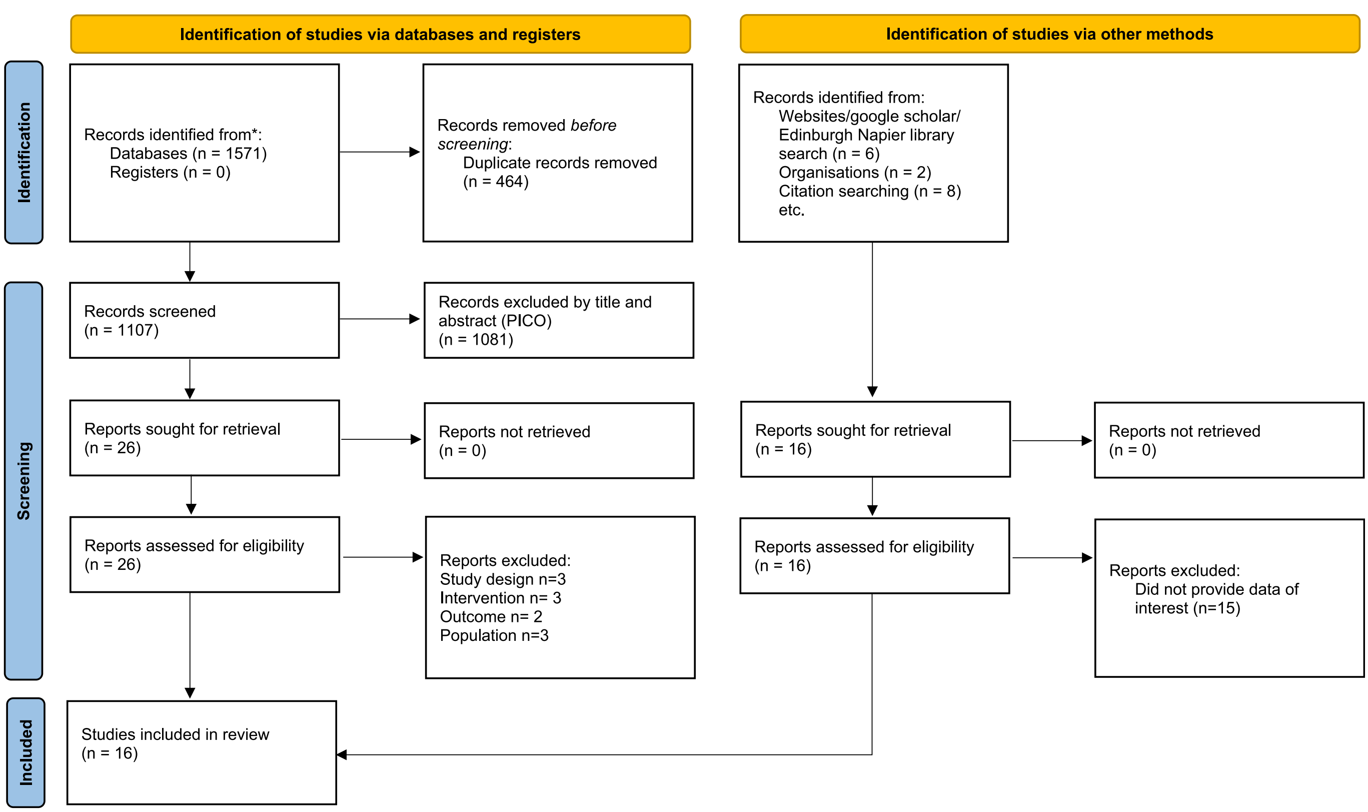

Fig. 1. PRISMA 2020 flow diagram for new systematic reviews(Page et al., 2021).

et al., 2022; Schneider et al., 2020; Tiwari et al., 2019; Zlotos et al., 2016). For satisfaction measures, six studies used validated tools(Chan et al., 2021; J. Hanson et al., 2019, 2020; Pence, 2022; Turrise et al., 2020; Zaragoza-García et al., 2021), and one study used a validated tool with modification (Persoulla et al., 2020). For confidence measure, three studies used standard validated tools (Pence, 2022; Turrise et al., 2020; Zaragoza-García et al., 2021) and one used a self-designed without discussing the validity (Zlotos et al., 2016).

3.2. Nature of intervention

All 16 studies reported that the method for delivering the interventions was computer-based; however, there were four studies whose intervention was also compatible with mobile phones(Chan et al., 2021; Giordano et al., 2020; Hanson et al., 2019, 2020; Schneider et al., 2020). Six studies used virtual simulation as a method of teaching pharmacology content(Abdel Haleem et al., 2023; Pence, 2022; Persoulla et al., 2020; Turrise et al., 2020; Zaragoza-García et al., 2021; Zlotos et al., 2016). Another six studies used computer simulation, with three specifically using 3D videos (Hanson et al., 2019, 2020; Saastamoinen et al., 2022; Thompson et al., 2020) and three using computer-based simulations with no specification on the dimension of video (Dubovi et al., 2018; P et al., 2018; Tiwari et al., 2019). Two studies used virtual reality technology (Chan et al., 2021; Giordano et al., 2020) and two studies used mixed reality (Veer et al., 2022) and augmented reality (Schneider et al., 2020).

The approach to simulation-based pharmacology courses varied between groups of students. The majority of studies described simulation interventions using problem case-based learning. In two studies, medical students applied pharmacology to the management of a specific disease (Persoulla et al., 2020; Veer et al., 2022), and in three, applied a virtual laboratory animal experiment (Abdel Haleem et al., 2023; P et al., 2018; Tiwari et al., 2019). In six studies, nursing students utilised the patient case scenario involving medicine administration (Chan et al., 2021; Giordano et al., 2020a; Pence, 2022; Saastamoinen et al., 2022; Turrise et al., 2020; Zaragoza-García et al., 2021) and in three studies models illustrating the pharmacokinetics and pharmacodynamics of certain drugs in the body were simulated (Dubovi et al., 2018; J. Hanson et al., 2019, 2020). In two studies, pharmacy students were given a patient-case scenario focusing on the context of medicine-dispensing instructions(Schneider et al., 2020; Zlotos et al., 2016). There was no multiple-user or teamwork-focused simulation. The above findings suggest that there was a diverse range of simulation interventions, and pharmacological content was present in all the interventions, either fully or partially.

3.3. Knowledge

Fourteen articles reported the impact of digital pharmacology-based simulations on knowledge acquisition and retention. 13 of these reported a positive impact on knowledge (Abdel Haleem et al., 2023; Chan et al., 2021; Dubovi et al., 2018; J. Hanson et al., 2019, 2020; P et al., 2018; Pence, 2022; Persoulla et al., 2020; Saastamoinen et al., 2022; Schneider et al., 2020; Tiwari et al., 2019; Turrise et al., 2020; Veer et al., 2022; Zaragoza-García et al., 2021; Zlotos et al., 2016) and one reported no significant change in knowledge (Giordano et al., 2020).

Eleven studies measured knowledge acquisition by comparing digital simulation(experimental) with other forms of teaching (control)(Chan et al., 2021; Dubovi et al., 2018; Giordano et al., 2020; J. Hanson et al., 2019, 2020; P et al., 2018; Persoulla et al., 2020; Saastamoinen et al., 2022; Turrise et al., 2020; Veer et al., 2022; Zaragoza-García et al., 2021). Of these, six studies reported significantly higher knowledge scores in the experimental group (Chan et al., 2021; Dubovi et al., 2018; Hanson et al., 2019; Persoulla et al., 2020; Zaragoza-García et al., 2021; Zlotos et al., 2016) and one reported a higher knowledge score in comparison with control group (P et al., 2018). Two studies reported that although knowledge was increased in both groups, there was no significant difference in scores when the study and control groups were compared (Hanson et al., 2020; Saastamoinen et al., 2022). One study reported no significant change in knowledge score in comparison with the control group (Giordano et al., 2020) and one study reported that the score was lower in the experimental group(Veer et al., 2022).

Three studies measured knowledge retention over time(Giordano et al., 2020; Veer et al., 2022; Zlotos et al., 2016). Giordano et al. (2020) reported that there was no significant difference in knowledge retention from the pre-test to three weeks baseline (38.9), and after three weeks (38.5) follow-up ($p = 0.229$). In two studies, the knowledge score was increased from the pre-test; however, there was no significant difference in retention score after two weeks of post-test (Veer et al., 2022) and some retention six months later (Zlotos et al., 2016).

3.4. Satisfaction and confidence

Seven studies reported the level of satisfaction among students after using digital simulation-based pharmacology (Chan et al., 2021; J. Hanson et al., 2019, 2020; Pence, 2022; Persoulla et al., 2020; Turrise et al., 2020; Zaragoza-García et al., 2021). In all studies the overall impact on satisfaction was positive. As evidence, satisfaction levels showed a high median of 4.6 [4.0–4.8] out of 5 in a study by Zaragoza-García et al., (2021). Similar positive outcomes were observed in two studies that assessed the post-simulation satisfaction scores (Chan et al., 2021; Pence, 2022). In four studies, group comparisons revealed higher levels of satisfaction in the experimental group i.e. higher in the 3D simulation when compared to the 2D(Hanson et al., 2019), higher in the 3D simulation when compared to 3D handheld device levels($p = 0.013$) (Hanson et al., 2020), higher in virtual simulation when compared to case studies (Turrise et al., 2020) and higher in virtual patients when compared to case-based discussions ($P = 0.01$)(Persoulla et al., 2020).

Four studies reported students' confidence levels after participating in a simulation-based pharmacology course(Pence, 2022; Turrise et al., 2020; Zaragoza-García et al., 2021; Zlotos et al., 2016). In all studies the overall impact on confidence was positive. In one study, group comparison revealed higher confidence in virtual simulation when compared to case studies (Turrise et al., 2020). The remaining three studies reported on post-simulation confidence levels(Pence, 2022; Zaragoza-García et al., 2021; Zlotos et al., 2016). One study highlighted a positive impact on mastery of content, skill development, and knowledge acquisition (Pence, 2022), while the other reported an increase in self-confidence in learning (Zaragoza-García et al., 2021). One study measured confidence levels at two time points over a six-month period and reported high levels of confidence in learning in both time points (Zlotos et al., 2016).

4. Discussion

Our study sought to examine the types of interventions and the impact of digital simulation-based pharmacology courses on three domains: knowledge, satisfaction, and confidence of pre-registration healthcare students.

The interventions used were diverse in nature, context, design, and devices. The majority of simulation interventions were delivered via computer devices and some from mobile phone-compatible devices. Interestingly, the advanced technology simulation belonged to western nations. Possible explanations for this could be cost-effectiveness (Farra et al., 2019; Mao et al., 2021) and accessibility (Foronda et al., 2016; Makransky and Petersen, 2019). Previous studies have identified that technology-enhanced learning benefits student learning (Dunn and Kennedy, 2019), and that smartphone-based mobile learning has a significant positive influence on nursing students' knowledge, skills, and attitudes (Kim and Park, 2019). In addition, such devices have been shown to be effective low-cost alternatives(Chandran et al., 2022). This indicates the potential for expanding the applications of such devices to deliver simulations. Using mobile phone technology will broaden the reach of simulated learning and aid educational institutions and simulation designers in developing affordable and accessible teaching techniques rather than costly high-quality technological equipment. This will ensure that education and training are available to all communities regardless of their economic status, thereby promoting equitable healthcare education globally.

All studies created single-user simulation, yet within, healthcare systems worldwide, there is a growing emphasis on interprofessional collaboration (IPC) and interprofessional education (Meyer et al., 2017). Moreover, interprofessional collaboration in healthcare has been shown to reduce avoidable adverse drug events and enhance patient safety (Grimes and Guinan, 2023; Labrague et al., 2018). Likewise, intraprofessional teamwork is essential to promote a unified approach to patient care and ensure coordinated care delivery(Gobis et al., 2018; Ylitörmänen et al., 2023). Debates are ongoing regarding the best way to conduct intra and interprofessional education and the optimal time in the curriculum to incorporate these activities (Teheux et al., 2021; Truong et al., 2022; van Diggele et al., 2020). The paucity of multi-user intra and interprofessional digital simulation was evident in this review, yet the reasons for this are unclear. Cost, digital literacy, compatibility of devices, and user expertise may be reasons for the absence of simulation development in this area. This suggests that further developmental work and research into the feasibility and acceptability of multiple-user (interprofessional/intraprofessional) digital simulation is necessary.

Simulation-based pharmacology courses varied according to the group of students. There was a diverse range of simulation interventions, and pharmacological content was present in all the interventions, either fully or partially. However, there was a paucity of high-quality research on digital simulation-based courses focusing solely on medicine optimisation and polypharmacy. The 2021 National Overprescribing Review in England revealed that around 15 % of the population regularly receive prescriptions for five or more medications (Department of Health and Social Care UK, 2021). Comparable trends are observed in other developed countries like the United States, where roughly 20 % of individuals in community settings experience polypharmacy(Delara et al., 2022). Polypharmacy is associated with patient safety and adverse health concerns. Conducting effective medicine reviews is crucial to identify and mitigate these risks, optimise medication regimens, and improve patient outcomes (WHO, 2019). The current literature suggests that educating healthcare professionals on the complexities of medicine optimisation reduces medicine-related harm, enhances person-centered care, and promotes realistic medicine (Barber and Jubraj, 2017; Cleary-Holdforth and Leufer, 2013; NHSinform, 2022). Therefore, more simulation interventions and related research focussing on medicines reviews and polypharmacy would be welcomed.

This study aimed to investigate formats of digital simulation-based pharmacology courses among all pre-registration healthcare students. However, it only identified relevant studies involving nursing, medicine, and pharmacy students. Most of the studies were from nursing, followed by medicine and pharmacy students. This limitation highlights the need for future research to include a broader range of healthcare disciplines. Previous reviews have shown that the use of virtual patients and simulation courses is a well-established component of the pharmacy curriculum(Beshir et al., 2022; Fens et al., 2020). Similarly, some evidence has illustrated the feasibility and usability of digital simulations in pharmacy education (Ezeala, 2020; Li et al., 2021). Although the number of reported studies was higher in this review, the integration of digital simulation-based pharmacology courses into pre-registration nursing curricula is still in its infancy. Moreover, among pre-registration pharmacy, medicine, and nursing students, we found that there is a paucity of evidence investigating the impact of such interventions on knowledge, satisfaction, and confidence. Therefore, another possible area of future research is to investigate the impact of digital simulation-based pharmacology courses on knowledge, satisfaction, and confidence among pre-registration students to fully understand the potential impact of digital simulation on pharmacology and the application of medicines knowledge to clinical situations.

Our objective was to explore the effect of digital pharmacology-based simulation courses on knowledge, and in 13 of the 14 included studies, there was a positive impact. This is consistent with a recent study published that investigated the effect of pharmacology knowledge using virtual reality (Kim et al., 2023). It reported a significant positive impact on knowledge acquisition, which is consistent with our findings in this review. Only a few studies reported decreased or similar changes compared to other forms of teaching in our study. This is in line with findings from Courteille et al. (2018) and Weston and Zauche (2021) where no significant difference in knowledge was identified. This implies that virtual simulation is as effective as, if not more effective than other instructional methods and can be an effective approach to pharmacology learning.

Despite the benefits of simulation-based pharmacology courses for knowledge acquisition, little research has been conducted to evaluate the impact on knowledge retention over different time points. In our review, three studies showed evidence of knowledge retention after two weeks, three weeks, and six months. A systematic review by Cook et al. (2010) has stated that virtual simulation teaching primarily focuses on short-term knowledge. Assessing knowledge retention over time provides insight into students' ability to apply learned concepts in real-world scenarios, which is essential for ensuring professional competency. By measuring knowledge retention longitudinally, educators can identify areas where additional support may be needed to help students achieve competence in their future roles as healthcare providers. Further investigation is warranted to determine the impact of such interventions on knowledge retention over time. This can support nurse educators and other healthcare educators by informing them about educational program improvements and validating the efficacy of different learning interventions (Hanshaw and Dickerson, 2020; Rahouti et al., 2021).

The five studies in this review implemented simulations using a blended approach i.e., simulation in combination with other forms of teaching. The findings of this review are in line with studies by Eom et al. (2021) and Sterner et al. (2023) that have shown the positive impact of blended simulations on students' learning outcomes. This highlights the effectiveness of blended teaching with virtual simulation as a strategy for running pharmacology courses. Therefore, further studies should be conducted on the best instructional design combinations for achieving better learning outcomes. This will help nursing educators and others plan more effective simulation-based education.

Concerning satisfaction and confidence in learning, few studies have examined the level of confidence and satisfaction with simulation-based pharmacology courses. Interestingly, all the studies reported a positive impact on satisfaction and confidence. The pattern of simulation training itself (pre-brief, simulation, and debriefing) could be one of the reasons that students were satisfied and confident, as claimed by various authors(Gu et al., 2017; Zapko et al., 2018).

5. Limitations of the review

As this analysis primarily searched and selected studies from seven databases, some unpublished studies may have been excluded.

6. Conclusion

The current review explored the types and effectiveness of digital simulation-based pharmacology courses in specific aspects of student learning, such as knowledge, confidence, and satisfaction; there remains a gap in understanding how these types of simulations contribute to preparing pre-registration students for licensure or practice. Investigating the relationship between such simulation courses and outcomes related to licensure, practice readiness, and interprofessional learning could provide valuable insights into the efficacy of these educational tools and inform best practices in healthcare education. Additionally, such research could help identify areas for improvement and guide the development of interventions to better support students as they transition from education to professional practice. Therefore, further research is needed to enhance the existing literature on the application of digital simulation in pharmacology education for nurses and other healthcare students.

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Sharad Rayamajhi: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Alison Machin:** Writing – review & editing, Supervision. **Cathal Breen:** Writing – review & editing. **Gdiom Gebreheat:** Validation. **Ruth Paterson:** Writing – review & editing, Visualization, Supervision, Conceptualization.

Declaration of competing interest

The authors report no conflicts of interest in this work.

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