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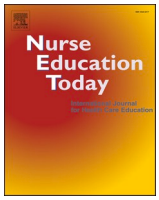

Research article

The effectiveness of serious games in nursing education: A meta-analysis of randomized controlled studies

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ABSTRACT

Objective: This systematic review and meta-analysis aimed to synthesize the effects of randomized controlled trials using serious gaming in nursing education on knowledge, skills, and confidence.
Design: Systematic review and meta-analysis of randomized controlled trials.
Data sources: Randomized controlled trials published in English in PubMed, CINAHL, Web of Science, Scopus, Cochrane Library databases between 2000 and 2023.
Review methods: Quality assessment was performed using the Joanna Briggs Institute Critical Appraisal Tool for Assessment of Risk of Bias for Randomized Controlled Trials and the review was reported according to the PRISMA-2020 protocol. The review was conducted by two independent reviewers.
Result: As a result of the database review, a total of 1886 studies were found and 8 studies were included in the meta-analysis. The use of serious games was found to have a low to moderate effect on the knowledge levels of nursing students (Hedge's g = 0.492; 95 % CI = −0.094–1.078), and a moderate effect on their skill (Hedge's g = 0.756; 95 % CI = 0.505–1.003) and self confidence levels (Hedge's g = 0.698; p = 0.362, 95 % CI = −0.801–2.196). The heterogeneity of the studies was found to be high for knowledge (I^2 = 92 %), skill (I^2 = 71.5 %) and self confidence (I^2 = 95.9 %), and low for knowledge (p = 0.90; p = 0.29) and skill (p = 0.75; p = 0.69) in terms of bias analyses egger regression test and begg and mazumdar test, respectively.
Conclusion: The reviewed studies revealed that the use of serious games in nursing education has positive effects on knowledge, skills and self-confidence. In order to increase the reliability of the evidence, there is a need to increase the number of welldesigned randomized controlled trials using serious games and to examine the effects of these results in clinical practice with larger sample groups.

1. Introduction

Nursing education consists of three complementary components: theoretical, laboratory, and clinical practice (Ngozika Ugwu et al., 2023; Tasdelen and Zaybak, 2013). The main purpose of this education is to prepare nursing students to deliver effective and appropriate care (Mankan et al., 2016; Ozsaban and Bayram, 2020). A basic goal in nursing education is to cultivate students' attitudes and skills across cognitive, affective, and psychomotor domains in theoretical and clinical practice (Karadag et al., 2013). Nursing students must possess a comprehensive skill set to navigate complex and dynamic clinical practice environments and provide individualized and holistic nursing care (Mannino et al., 2021). Ensuring that nursing students are confident and competent in the clinical practice environment and improving patient care outcomes are essential (Mlinar Reljić et al., 2019). In this context, acquiring consistent knowledge and skills in professional practice plays a key role in ensuring safe and effective care (Ngozika Ugwu et al., 2023). Hence, students need to start clinical practice in the first year of their education (Admi et al., 2018). However, the complex nature of the clinical practice environment is a significant source of stress for nursing students (Mlinar Reljić et al., 2019). A review of the literature revealed nursing students stating that they experienced anxiety and worry because of not meeting patient expectations in the clinical environment, worry about harming patients, fear of giving wrong information and making an incorrect/incomplete application, fear of encountering infectious diseases and having sharps injuries, difficulty in

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developing relationships with health professionals, professional incompetence, and fear of making mistakes in hospital procedures (Cambridge et al., 2023; Mankan et al., 2016). A systematic review of the difficulties experienced by nursing students in clinical practice showed that first- and second-year students experienced more anxiety during the caregiving process. Also, students had problems adapting to the clinical practice environment because the objectives of theoretical education did not overlap with clinical practice, and laboratory practices were not effective and efficient (Ozsaban and Bayram, 2020).

Nursing students stated that their experiences in clinical practice were mainly influenced by their relationships with patients, clinical instructors, and other nursing students in their groups. Also, they experienced feelings of inadequacy, being ignored by health professionals working in the clinic, ineffective communication, indecision, and fear of harming the patient (Cambridge et al., 2023). Inadequate knowledge, skills, and behavioral gains in students' clinical practice experiences caused a deficiency in self-confidence and self-efficacy, anxiety, and stress in clinical practice.

Performing practical skills in laboratory applications is extremely important for students to gain sufficient knowledge, skills, and self-confidence before starting clinical practice (Leflore et al., 2012; Tan et al., 2017). In general, the psychomotor skill competencies of students are practiced in the laboratory by nurse educators on manikins simulator or skill videos or through demonstration by the trainer. Nursing students often need to learn multiple skills simultaneously in a short time and have limited access to laboratory environments to practice these skills (Aebersold et al., 2018). However, given the development of technology, the expectations of students, and the continuous updating of knowledge in today's changing scenario, the methods traditionally used in laboratory applications have increased the need for additional teaching strategies and materials for enhancing knowledge and skills (Bayram and Caliskan, 2019; Chang et al., 2021; Leflore et al., 2012). Therefore, nurse educators need to use new teaching techniques to attract students' attention (Min et al., 2022; Tan et al., 2017).

Simulation applications, simulated patients, and serious games as a new pedagogical approach to teaching skills in nursing education constitute essential teaching strategies preferred by educators in health education (Bayram and Caliskan, 2019; Karaduman and Basak, 2023; Tan et al., 2017). Strategies such as a life-sized anatomical human model, virtual augmented reality applications, serious games, and so forth are used to prepare nursing students for clinical practice, enabling them to experience the real hospital environment and gain experience without risking patient safety (Aebersold et al., 2018; Bayram and Caliskan, 2019; Boada et al., 2015; Karaduman and Basak, 2023; Leflore et al., 2012; Tan et al., 2017). Serious games are defined as interactive computer applications developed for educational purposes, with or without hardware assistance. They consist of challenging objectives/goals, entertain while playing, contain specific scoreboards, and aim to provide knowledge and skills to the player in line with the defined objectives (Tan et al., 2017).

Serious games, especially those with a simulation component, have gained interest in nursing education to support the development of students' knowledge, skills, satisfaction, and self-confidence (Boada et al., 2015; Karaduman and Basak, 2023; Leflore et al., 2012). Serious games in the development of basic skills are defined as interactive computer applications that present a challenging goal, offer an enjoyable and engaging experience, incorporate scoring mechanisms, and equip users with useful skills, knowledge, or attitudes. They provide students with opportunities for active learning, solving clinical problems, and gaining experience in a risk-free environment (AL-Mugheed et al., 2022; Gentry et al., 2019). These approaches help students develop their analytical skills, clinical reasoning, problem-solving and decision-making skills, knowledge, clinical performance, multitasking, communication, self-efficacy, self-confidence, and psychomotor skills by actively engaging in the subject matter (Aebersold et al., 2018; Tan et al., 2017).

Increased student satisfaction with serious games not only facilitates student access to information during the learning process but also increases the retention of knowledge and skills (Gentry et al., 2019). Further, it enables the education of many students at the same time, during learning or practice, especially in places with no nurse educator, thereby enhancing skill acquisition across various environments. In particular, global disasters and pandemics interrupt students' face-to-face learning, and new strategies, such as serious games, prevent students from interrupting their learning of knowledge and skills (AL-Mugheed et al., 2022; Min et al., 2022).

Simulation-based education has become the basic building block of undergraduate nursing education. It is crucial to integrate serious games, which include the subcomponent of simulation, into nursing education and evaluate their effectiveness. This meta-analysis was conducted to examine randomized controlled trials (RCTs) on the effectiveness of serious games in nursing education.

2. Materials and methods

This systematic review and meta-analysis of RCTs was reported according to the PRISMA 2020 protocol (Page et al., 2021) and registered with PROSPERO (International Prospective Register of Systematic Review (Registration no: CRD42023459525). The PICOS strategy used in the review was summarized as follows. The research questions were determined in line with PICOS (participants/population: undergraduate nursing students; intervention(s), exposure(s): computer-assisted game types [virtual game, serious game, digital game]; comparator(s)/control: groups/individuals not exposed to any virtual simulation–serious gaming–digital gaming; outcomes: knowledge, skills, and degree of self-confidence; study design: RCT) as follows. Serious games are also defined as "virtual simulation/digital games/serious games" in the literature because they include interactive video simulations with animations and moving visuals (Kelly et al., 2007; Montagni et al., 2020). Therefore, in this study, simulation games and digital games played in a virtual environment are also considered and analyzed as serious games.

- What are the types of computer-assisted games used in undergraduate nursing education?
- What is the effect of virtual simulation/digital games/serious game–based educational games on students' knowledge, skills, and self-confidence levels?

2.1. Inclusion and exclusion criteria

Individuals born in and after 2003, defined as Generation Z, were born into a period when communication and information technologies were rapidly evolving and changing. Therefore, educators have needed different teaching and learning methods to meet the educational needs of this generation (Kavalci and Unal, 2016). Educational games that can be played in virtual environments, one of the technologies offered by today's world, are seen as an opportunity for teaching cognitive and psychomotor skills to Generation Z (Avci and Avsar, 2016). Serious games, by attracting the player's attention and offering teaching opportunities at relatively low costs, have become increasingly demanded due to their usability and flexibility (Dankbaar et al., 2017). Additionally, an increase in serious games has been reported in the literature towards the end of the 20th century (Djaouti et al., 2011). Therefore, studies conducted after the year 2000 were included in this research.

Inclusion criteria: The inclusion criteria were as follows: studies including RCTs; studies using virtual simulation games, serious games, digital games, and computer-assisted games; studies focusing on knowledge and skill learning outcomes of nursing students; and studies published in English in national and international refereed journals between 2000 and 2023.

Exclusion criteria: The exclusion criteria were as follows: studies

whose full text could not be accessed; studies that did not meet the research purpose and learning outcomes; simulation techniques and educational games that did not include computer-aided games; studies conducted with health sciences faculty students other than nursing undergraduate students, nurses, other health professionals, physicians, educators, and patients; quasi-experimental studies; theses, systematic reviews, and meta-analyses; books and book chapters; reviews; expert opinions; editorials; letters to the editors; case reports; congress–conference proceedings; non-skilled research; pilot and design studies; and studies conducted through distance education.

2.2. Search strategy

PubMed, CINAHL, Web of Science, Scopus, and Cochrane Library databases were searched. A pilot study with two authors was conducted before starting the review. The following keywords were used: ("serious game" OR "digital game" OR "virtual simulation") AND ("nursing education") AND ("nursing students"). Since virtual simulation and serious games can be used for educational purposes and gamification, an additional search was conducted in Scopus and PubMed databases with the keywords "educational game" OR "gamification" (Appendix 1).

2.3. Data extraction

After all studies accessed as a result of the search were transferred to the EndNote 20 resource screening program, duplicate studies and studies eliminated in line with the research title, purpose, and questions were removed. The full texts of the remaining studies were downloaded and saved. Two authors who independently applied the inclusion and exclusion criteria reviewed the studies. Studies that did not meet the criteria were excluded from the study sample. Disagreements were resolved by discussion, and if consensus could not be reached, the third author was consulted. The studies were selected following the PRISMA flowchart. During data extraction, both researchers used the data extraction form consisting of "Author/Year/Country," "aim," "participants and features," "data collection tools/debriefing," "type of game," "findings," and "competency domain."

2.4. Quality assessment

Joanna Briggs Institute (JBI) Critical Appraisal Tool for Assessment of Risk of Bias for Randomized Controlled Trials was used for quality assessment of the included studies. The permission to use the tool was obtained from Hur et al. (2022), who adapted the tool to the Turkish language to ensure that the statements in the tool were perceived correctly by the language of the researchers. All studies included in the review were examined in accordance with the 13 questions in the JBI RCT checklist. All studies were evaluated by two independent researchers for bias according to the "yes," "no," "unclear," and "not applicable" markers of each question in the checklist, and the quality of the studies was determined (Table 1). Disagreements were resolved through assessment by a third researcher.

2.5. Data analysis

The data were analyzed using the Comprehensive Meta-Analysis-4 software program. The weighted averages of the studies included in the meta-analysis and their effects on knowledge, skills, and self-confidence outcomes were calculated in line with the 95 % confidence interval (CI). Hedge's coefficient (large = $d \geq 0.80$; medium = $0.20 < d < 0.80$; small = $d \leq 0.20$) was used in data synthesis due to the differences in the sample sizes of the studies (Borenstein et al., 2007). The heterogeneity of the studies was determined using the I^2 test and p statistic. According to the classification of I^2 test statistics (low, $I^2 < 25$ %; medium, 50 %; and high, $I^2 > 75$ %) (Borenstein et al., 2021), the I^2 test statistics of knowledge, skills, and self-confidence learning outcomes was >50 %, and hence the meta-analysis was heterogeneous. The analysis results were determined according to the random-effects model. Egger's regression test, Begg and Mazumdar's test, and Rosenthal's N number were used in the bias analysis evaluation.

3. Results

3.1. Study selection

As a result of the database review, 1886 studies were found (PubMed = 572, CINAHL = 536, Cochrane Library = 524, Scopus = 87, Web of Science = 147). After eliminating duplicate studies ($N = 578$) and those with inappropriate titles and abstracts ($N = 1234$) and applying exclusion criteria ($N = 64$), 10 studies were included for meta-analysis. Two studies lacked appropriate statistical analyses and hence were excluded, resulting in the meta-analysis of only eight studies (Fig. 1).

3.2. Study characteristics

All studies included in the analysis were RCTs. Two of the studies (Farsi et al., 2021; Karaduman and Basak, 2023) included two experimental groups, one serious game group and the other non-virtual

Table 1
Studies' scores on the JBI tool and quality indicators.

		JBI CHECKLIST													
Study No	Author, year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Quality Class
1	Aebersold et al., 2018	Y	U	Y	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	A
2	Al-Mugheed et al., 2022	Y	U	Y	U	U	U	Y	Y	Y	Y	Y	Y	Y	B
3	Bayram & Caliskan, 2019	Y	U	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	Y	A
4	Chang et al., 2021	Y	Y	Y	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	A
5	Farsi et al., 2021	Y	N	Y	U	U	Y	Y	Y	Y	Y	Y	Y	Y	B
6	Karaduman &Basak, 2023	Y	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	B
7	Leflore et al., 2012	Y	U	Y	U	U	U	Y	Y	Y	Y	Y	Y	Y	B
8	Tan et al., 2017	Y	U	Y	U	U	U	Y	Y	Y	Y	Y	Y	Y	B

Y = Yes, N = No, U = Unclear.

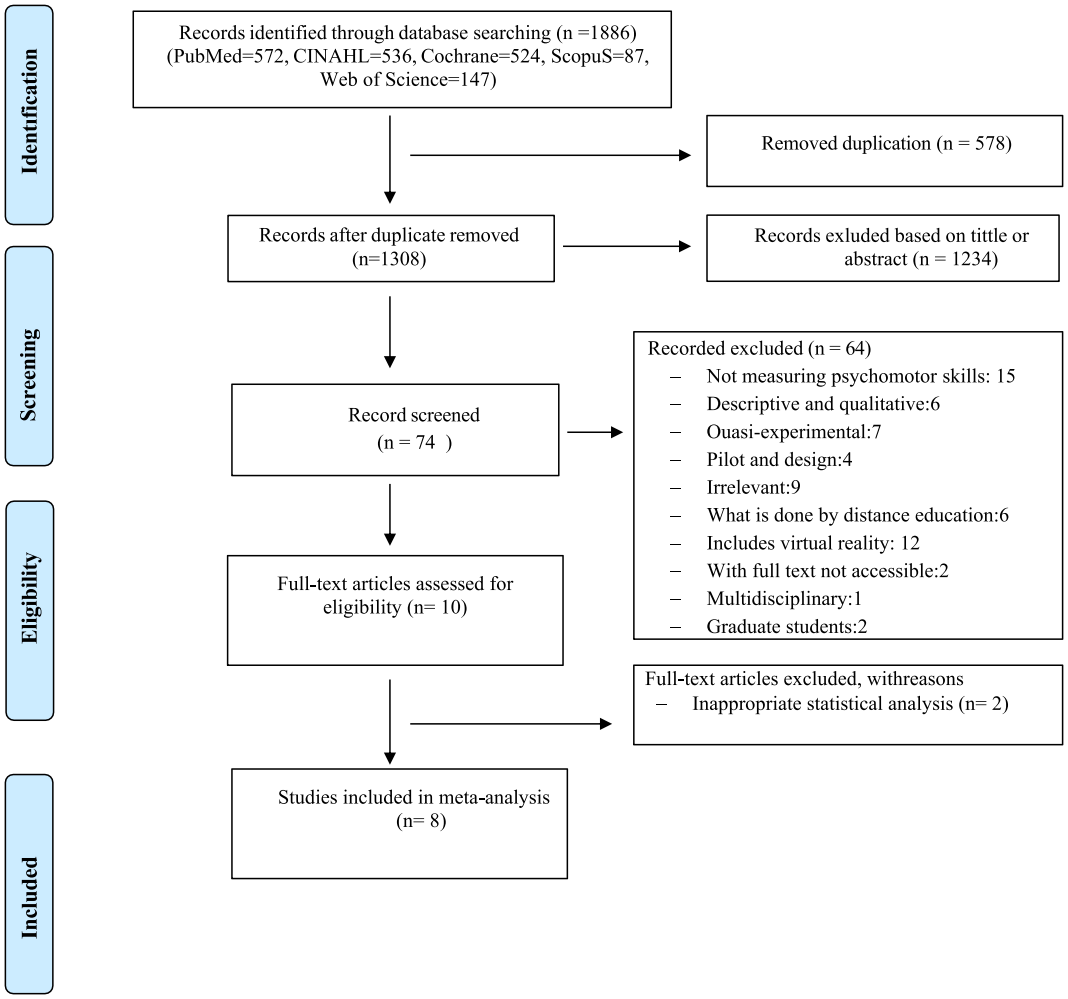

Fig. 1. Systematic review and meta-analyses (PRISMA) flow diagram.

simulation group. Therefore, the data of the non-virtual simulation groups of these studies are given in Table 2 but were not included in the meta-analysis and comparisons were made between the serious game and control groups. The sample size of the analyzed studies varied between 36 and 122 and comprised undergraduate nursing students. The total sample size was 693. The studies, which included experimental and control groups and measured the outcomes of knowledge, skills, and self-confidence, satisfaction, attitude, and anxiety in nursing education, were conducted in six different countries: the USA ($n = 2$, 25 %), Türkiye ($n = 2$, 25 %), Singapore ($n = 1$, 12.5 %), Iran ($n = 1$, 12.5 %), Northern Cyprus ($n = 1$, 12.5 %), and Taiwan ($n = 1$, 12.5 %). 3 studies (37.5 %) were conducted in 1st grade, 1 study (12.5 %) in 2nd grade, 1 study (12.5 %) in 3th grade, and the other 3 studies were conducted in mixed grades. Practical and validated checklists and scales were used to assess outcomes in knowledge, skills, and self-confidence. The characteristics of these studies are presented in Table 2.

In the studies included in the meta-analysis, theoretical and laboratory training was provided by the instructors to the experimental and control groups individually or in groups. In 5 studies (Aebersold et al., 2018; Bayram and Caliskan, 2019; Karaduman and Basak, 2023; LeFlore et al., 2012; Tan et al., 2017), participants took part in the training given to both experimental and control groups as a group, in 1 study (Al-Mugheed et al., 2022), they took part individually in the experimental group and divided into small groups in the control group. In 2 studies (Chang et al., 2021; Farsi et al., 2021), no pre-intervention training was provided, and students' prior learning was taken into account. Participants in the experimental groups in all studies played the games individually and were evaluated individually. In 5 of the studies (Aebersold et al., 2018; Farsi et al., 2021; Karaduman and Basak, 2023; LeFlore et al., 2012; Tan et al., 2017), post-intervention debriefing sessions were held, and feedback was given. The studies included in the meta-analysis included virtual simulation (Aebersold et al., 2018; Chang et al., 2021), virtual patient simulation (Farsi et al., 2021; Karaduman and Basak, 2023; LeFlore et al., 2012; Tan et al., 2017) virtual reality (AL-Mugheed et al., 2022; Bayram and Caliskan, 2019) technologies and can be played with mobile devices such as tablets and mobile phones (Table 2).

In the studies included in the meta-analysis, the effect sizes for knowledge, skills, and self-confidence outcomes were calculated. Satisfaction, attitude, and anxiety outcomes were not included in every study. The effect sizes of these outcomes could not be calculated due to the lack of studies including these outcomes together.

3.3. *Quality of studies*

All studies included in the analysis were evaluated by two independent authors using the JBI RCT tool, and consensus was reached in all studies. The studies were classified as A (high quality), B (moderate quality), and C (low quality). Three of the reviewed studies met at least 11 criteria of the JBI tool. The other two criteria that were not met were evaluated as "unclear" and were therefore evaluated as A quality. Since the other studies had more than two "unclear" results and at least one "no" result, these studies were evaluated as B quality. The scores and quality indicators of the studies from the JBI tool are provided in

Table 2
The characteristics of included studies.

Author/Year/ Country	Aim	Participants and features	Data Collection Tools/ Debriefing	Type of game	Findings INT/CONT (Knowledge, skill, self-confidence in learning and learning satisfaction)	Competency domain
Aebersold et al., 2018, USA	To measure effectiveness the impact of interactive virtual simulation on nasogastric tube (NGT) placement skills.	69 nursing 2nd and 3th year undergraduate students Intervention:34/Standard curriculum (group narration), animated video (group narration), iPad anatomy-augmented virtual simulation training module (individual playing) Comparator: Manikin based simulation Control:35/Standard curriculum (group narration)	NGT application checklist, Feasibility Evaluation/ Partial debriefing	iPad Anatomy-Augmented Virtual Simulation	Knowledge: - Skill: Post-test skill performance scores in intervention group (15,96 ± 0,75) significantly higher overall to control group (15,39 ± 1,01) (p=0,011). Self Confidence: - Perception: The AR group also perceived AR as interactive and novel, as well as significantly more useful in identifying landmarks and visualizing internal structures (p < 0,001).	Procedural skills
Bayram and Caliskan, 2019, TURKEY	To determine the effect of a game-based virtual reality phone application on tracheostomy care education for nursing students.	86 nursing 1st year undergraduate students Intervention:43/power point presentation of tracheostomy (group narration), tracheostomy care demonstration on manikin (group narration), game-based virtual reality application (individual playing) Comprator: Manikin based simulation Control: 43/power point presentation of tracheostomy (group narration), tracheostomy care demonstration on manikin (group narration)	Descriptive Characteristics Questionnaire, Tracheostomy Care Information Test, Tracheostomy Care Skill Checklists/Nil	Game-based virtual reality phone application	Knowledge: No statistically significant difference observed between the first knowledge and last knowledge scores; however, the last knowledge scores of the control and experimental groups increased (p > 0.05). Skill a: No statistically significant difference was observed between the first scores for the suctioning skill of the control and intervention groups (p > 0.05). But the last skill performance scores of the students in the intervention group were significantly higher than those of the control group (p = 0.017). Skill b: The first mean scores for the inner cannula cleaning skill of the students in the experimental group were significantly higher than the control group (p = 0.000). The last scores for this skill were also higher in the experimental group than the control group, but no significant difference was observed between the groups (p > 0.05). Skill c: The first and last peristomal skin care skill performance scores of the students in the experimental group were higher than those of the control group at a statistically significant level (p = 0.033, p = 0.003). Self Confidence: - Satisfaction: -	Procedural skills
Chang et al., 2021, TAIWAN	The effects of a virtual simulation- based, mobile technology application on nursing	100 nursing 1st and 2nd year undergraduate students Intervention:50/effect of	Knowledge assessment, Skill performance by direct observation of procedural skills,	Virtual simulation-based mobile	Knowledge: After the intervention, the mean level of knowledge in the experimental group (80.9	Procedural skills

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Table 2 (*continued*)

Author/Year/ Country	Aim	Participants and features	Data Collection Tools/ Debriefing	Type of game	Findings INT/CONT (Knowledge, skill, self-confidence in learning and learning satisfaction)	Competency domain
	students' learning achievement and cognitive load: Randomized controlled trial	virtual simulation-based mobile technology application (individual playing) Comparator: Manikin based Simulation Control: 50/traditional intervention (individual narration)	Cognitive load scale, satisfaction/Nil	technology application	± 9.12) was higher than in the control group (74.4 ± 9.61), ($p < 0.001$). Skill a: The mean scores of medication administration were significantly higher in the experimental group (6.33 ± 1.17) than in the control (5.29 ± 4.43) group ($p < 0.001$). Skill b: The mean scores of nasotracheal suctioning in the experimental group (6.70 ± 1.10) were significantly higher than of the control (1.32 ± 3.75) group ($p < 0.001$). Self Confidence: - Satisfaction: The experimental group (6.66 ± 1.58) had significantly higher satisfaction than the control (5.51 ± 1.35) group ($p < 0.001$).	
Karaduman and Basak, 2023, TURKEY	Evaluate the effects on nursing students of alone or combined use of HPS and VPS on performance, simulation-based learning.	126 nursing 3th year undergraduate students (İncluded:84) Intervention 1 (VPS): 42 two scenarios with Body Interact app (individual playing) *Intervention 2 (VPS and HPS group): 42 one scenario with Body Interact app and one scenario with CAE Juno manikin (individual playing) Comparator: CAE Juno manikin Control (HPS): 42 two scenarios with CAE Juno manikin (individual playing)	Nursing Anxiety and Self-Confidence with Clinical Decision-Making Scale, Simulation-Based Learning Evaluation Scale, Performance Assessment Forms, Student Feedback Form/Comprehensive debriefing	Virtual Patient Simulation (Body Interact app)	Knowledge: There was no statistically significant difference between the groups in terms of the knowledge scores (p > 0,05). But VPS and HPS intervention group's post-test knowledge scores (26.5 ± 4) higher than pretest scores (24.6 ± 3). Same time HPS control group's post- test knowledge scores (27.4 ± 4.8) higher than pretest scores (24.7 ± 3.5) ($p < 0.005$). Skills: The performance test results of the VPS and HPS intervention group (78.6 ± 8.5) were better than the HPS control group (68.1 ± 9.5) ($p < 0.001$). Self Confidence: The post-test self-confidence scores (120.4 ± 24.6;56,5 ± 28) of the VPS and HPS intervention group were higher than the pre-test scores (111.8 ± 21.3;65 ± 27,9) (p < 0.005). Anxiety: The post-test anxiety scores (122 ± 23,3;54,3 ± 18,4) of the HPS control group were better than the pre-test score (107,1 ± 19,6;65,7 ± 22,9) ($p < 0.005$). Satisfaction: -	Procedural skills
Farsi et al., 2021, IRAN	This study was aimed at estimating the effect of a simulation-based CPR training using a manikin in comparison with serious game.	54 nursing 1st year undergraduate students (İncluded:36) *Intervention 1 (Simulation group): 18/CPR training using a manikin (individual playing) Intervention 2 (Serious game group): 18 /CPR training using a serious	Demographic questionnaire, CPR Knowledge, and Skill tests/ Comprehensive debriefing	Serious game based mobile technology application	Knowledge: There is no significant difference between the simulation intervention group and the serious play group. However, in both groups, post-test (9:55 ± 2:81;7:77 ± 2:46) scores after training were higher than the pre-test (4:33 ±	Procedural skills

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Table 2 (*continued*)

Author/Year/ Country	Aim	Participants and features	Data Collection Tools/ Debriefing	Type of game	Findings INT/CONT (Knowledge, skill, self-confidence in learning and learning satisfaction)	Competency domain
		game (individual playing) Comparator: Manikin based simulation Control: 18/ Nil			1:87;6:22 ± 2:13) (p = 0.011). Skill: On the posttest, the simulation and serious game groups were significantly different from the control group. There are no significant difference skills scores between the simulation intervention group and the serious play group. However, in both groups, post-test scores (25:72 ± 3:98; 27:17 ± 2:81) after training were higher than the pre-test ($p < 0.001$). Self Confidence: - Satisfaction: -	
Al-Mugheed et al., 2022, CYPRUS	To evaluate the effectiveness of game-based virtual reality phone applications compared to traditional education.	122 nursing 3th and 4th year undergraduate students Intervention:63/Online course on standard precautions (individual narration)/Lessons on standard precautions e-learning platform (individual narration)/ standard precautions using game-based virtual reality phone applications (individual playing)/two hours laboratory demonstration (small group narration) Comprator:Nil Control:59/Online course on standard precautions (group narration) /Traditional teaching methods in the classroom regarding standard precautions (PowerPoint presentation slides, etc.) (group narration), laboratory course (group narration)	Demographic characteristics, CDC standard precautions knowledge and attitude, CDC standard precaution compliance checklist/Nil	Game-based virtual reality phone app	Knowledge: After the intervention, the experimental group (13.2 ± 2.7) had higher mean scores for standard precautions knowledge domains than the control group (12.3 ± 1.1) (p = 0.002) Attitude: After the intervention, the experimental group (11.2 ± 1.5) had higher mean scores for standard precautions attitude domains than the control group (9.3 ± 2.5) (p = 0.001) Skill: The game-based virtual reality phone application was more effective than the traditional method in demonstrating compliance skills with standard precautions (p = 0.002). The posttest skill scores (42.1 ± 5.6) of the play group were better than the pretest (23.5 ± 7.9) (p = 0.002). There was no difference between pretest (20.1 ± 5.8) and posttest (31.6 ± 6.3) in the control group (p = 0.15). Self Confidence: - Satisfaction: -	Procedural skills
LeFlore et al., 2012, USA	To measure the effectiveness of teaching a virtual patient compared to traditional training methods in teaching pediatric respiration.	93 nursing 1st year undergraduate students Intervention: 46/Textbook readings on respiratory diseases (individual reading), a standard simulation laboratory (group narration), virtual patient trainer game app (individual playing). Comparator: Simulation patient Control: 47/ Textbook readings on	Demographic characteristics, General knowledge test regarding the care of pediatric patients, OSCEs checklist/ Comprehensive debriefing.	Virtual patient trainer game app	Knowledge: The knowledge scores of the experimental group (83.9 ± 15) were significantly higher than the control group (75 ± 12) (p = 0.004). Skill: On the checklists for the two OSCEs measuring skills application, there were significant differences in times between the groups for all	Procedural skills

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Table 2 (*continued*)

Author/Year/ Country	Aim	Participants and features	Data Collection Tools/ Debriefing	Type of game	Findings INT/CONT (Knowledge, skill, self-confidence in learning and learning satisfaction)	Competency domain
		respiratory diseases (individual reading), a standard simulation laboratory (group narration), traditional course (group narration)			critical elements, with the experimental group demonstrating more timely performance of critical nursing tasks in the OSCEs ($p = 0.001$; for each of the two scenarios). Self Confidence: - Satisfaction: -	
Tan et al., 2017, SINGAPURE	To describe the development and evaluation of a serious game to improve nursing students' knowledge, confidence, and performance in blood transfusion	103 nursing 2nd year undergraduate students Intervention: 57/ Traditional course (group narration), laboratory class (group narration), serious game app (individual playing) Comparator: Simulated patient Control: 46/ Traditional course (group narration), laboratory class (group narration),	Knowledge Questionnaire, Performance, Tool, Perception Scale, Confidence Scale/ Comprehensive debriefing	Serious game app	Knowledge: The experimental group that received the serious game intervention (11.76 ± 2.26) had significantly higher posttest mean scores than the control group (16.46 ± 1.86) ($p < 0.001$). Skill: Based on the simulation-based assessment, the experimental group showed a higher performance score (24.91 ± 5.04) than the control group (22.89 ± 5.14). However, no significant difference was found in the performance mean scores between the two groups ($p = 0.105$). Self Confidence: The experimental group (31.56 ± 8.77) receiving serious gaming intervention showed significantly higher post-test confidence mean scores than the control group (19.39 ± 7.57) ($p < 0.001$) Satisfaction: -	Procedural skills

NGT: Nasogastric tube, HPS: Human patient simulation, VPS: Virtual patient simulation, CPR: Cardiopulmonary resuscitation, App: Application.
* These groups were not included in the analysis because they contained simulations.

Table 1. All studies in the meta-analysis included experimental and control groups, randomization was applied in each of them, participants were analyzed in the groups they were included in, and data analysis was performed with appropriate statistical methods. As stated in the PRISMA flowchart, two studies initially intended for inclusion in the meta-analysis were excluded due to their failure to utilize appropriate statistical methods, and their exclusion was duly reported.

3.4. Serious games in undergraduate nursing education

All studies included in the meta-analysis used computer-assisted or video-based serious games, virtual games, or digital games. These included a three-dimensional virtual simulation game enriched with iPad anatomy (Aebersold et al., 2018), a virtual phone game created using Adobe Flash Professional (AL-Mugheed et al., 2022), a virtual reality game designed using Adobe Flash Professional CC and Adobe Flash CS6 programs and playable with Android and Windows platforms (Bayram and Caliskan, 2019), a serious game–based mobile technology application (Farsi et al., 2021), a BodyInteract virtual patient simulator (Karaduman and Basak, 2023), a serious game that could be played via smartphones (Chang et al., 2021), a three-dimensional virtual game–based simulator (LeFlore et al., 2012), and a computer-based serious game (Tan et al., 2017). The effectiveness of the serious games used in the studies was measured through pre- and post-tests administered to the experimental and control groups. Psychomotor skill assessments were carried out in laboratory and classroom environments using skill assessment checklists. In seven studies, the effects of serious game use on knowledge level and the differences between groups were evaluated using a knowledge questionnaire. In two studies, the effects of serious game use on self-confidence were examined.

3.5. Impact of serious games on knowledge outcomes

Seven of the included studies comprised measures of learning outcomes for the knowledge component. These studies are as follows; standard precautions (AL-Mugheed et al., 2022), tracheostomy care (Bayram and Caliskan, 2019), drug administration and nasotracheal suction (Chang et al., 2021), cardiopulmonary resuscitation (Farsi et al., 2021), respiratory system problems (Karaduman and Basak, 2023), pediatric respiratory diseases (LeFlore et al., 2012), blood transfusion (Tan et al., 2017). The effects of serious games on knowledge outcomes were examined in 624 nursing students (experimental = 319, control = 305). The heterogeneity of the studies was high in terms of knowledge level ($I^2 = 92\ \%$, $p = 0.000$).

When the individual effect sizes (hedge's g) of the studies were examined, AL-Mugheed et al. (2022) ($g = 0.429$), Bayram and Caliskan

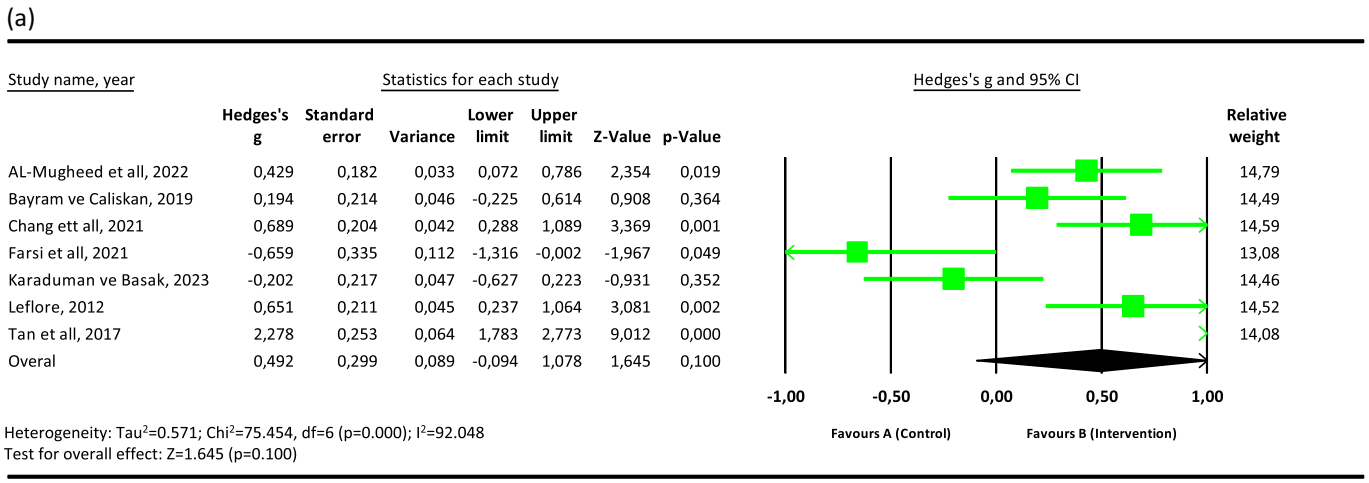

Fig. 2. (a) Forest plot of konowledge effect of serious games. (b) Forest plot of skill effect of serious games. (c) Forest plot of self-confidence effect of serious games.

(2019) (g = 0.194) Chang et al. (2021) (g = 0.689), Farsi et al. (2021) (g = −0.659), Karaduman and Basak (2023) (g = −0.202), LeFlore et al. (2012) (g = 0.651), Tan et al. (2017) (g = 2.278) were found. The pooled Hedges' g value from all studies was 0.492, with a p value of <0.100, 95 % CI = −0.094–1.078, and $z = 1.645$. According to the calculated effect size, serious games were found to have a low to moderate effect on knowledge output (Fig. 2a). In the bias analysis of the knowledge component, Eggers' regression test and Begg and Mazumdar's test statistics were found to be $p = 0.90$ and $p = 0.29$, respectively, and these values were not significant. Rosenthal's N number (5 K + 10) was used to calculate how many studies should be added to make the effect size insignificant in the meta-analysis of studies including knowledge measurement, and 59 studies were found. As this number was far from the number of studies including knowledge measurement ($n = 7$), the bias analysis was low in this study.

3.6. Effects of serious games on skill outcomes

A total of 8 studies were analyzed. The studies included in the meta-analysis nasogastric tube skills (Aebersold et al., 2018), standard precautions (AL-Mugheed et al., 2022), tracheostomy care (Bayram and Caliskan, 2019), medication administration and nasotracheal suctioning (Chang et al., 2021), cardiopulmonary resuscitation (Farsi et al., 2021), respiratory system issues (Karaduman and Basak, 2023), pediatric respiratory diseases (LeFlore et al., 2012), blood transfusion (Tan et al., 2017) comprised measurements of learning outcomes for the skill component. The effect of serious games on skill outcomes was examined in 693 nursing students (experimental = 353, control = 340). The

heterogeneity of the studies was high in terms of skill level ($I^2 = 71.5$ %, $p = 0.000$).

When the individual effect sizes (hedge's g) of the studies were analyzed, Aebersold et al. (2018) (g = 0.635), AL-Mugheed et al. (2022) (g = 1.754), Bayram and Caliskan (2019) (g = 0.568; g = 0.315; g = 0.679), Chang et al. (2021) (g = 0.878; g = 0.743), Farsi et al. (2021) (g = 0.412), Karaduman and Basak (2023) (g = 1.154), LeFlore et al. (2012) (g = 0.699), Tan et al. (2017) (g = 0.394) were found. The pooled Hedges' g value from all studies was 0.756, with a p value of 0.000, 95 % CI = 0.505–1.003, and $z = 5.989$. According to the calculated effect size, serious games had a positive effect on the skill component (Fig. 2b). In the skill component bias analysis, Egger's regression test p value was 0.75 and Begg and Mazumdar's test statistic p value was 0.69, and these values were found to be insignificant. The number of studies needed to be included for the effect size of the meta-analysis to be insignificant was calculated using Rosenthal's N number (5 K + 10), and 352 studies were found. As the number of included studies ($n = 8$) was far from this calculation, the risk of bias was low in the study.

3.7. Effects of serious games on self-confidence outcomes

Self-confidence results were included in two of the studies included in the meta-analysis (Karaduman and Basak, 2023; Tan et al., 2017). The effects of serious games on self-confidence outcomes were examined in 187 nursing students (experiment = 99, control = 88). The heterogeneity of the studies was high in terms of self-confidence level ($I^2 = 95.9$ %, $p = 0.000$).

When the individual effect sizes (hedge's g) of the studies were analyzed, Karaduman and Basak (2023) (g = −0.066), Tan et al. (2017) (g = 1.463) were found. The pooled Hedges' g value from two studies was 0.698, with a p value of 0.362, 95 % CI = −0.801 to 2.196, and $z = 0.912$ (Fig. 2c). According to the obtained Hedges' g value, serious games had a moderate effect on self-confidence. The data of at least three studies were required for bias analysis with funnel plots in the CMA-4 program, and only two of the studies included in this meta-analysis could examine the self-confidence dimension. Hence, bias analysis for the self-confidence component could not be performed.

4. Discussion

Educational games called "serious games" are a category of games that have emerged as a new pedagogical approach in nursing and healthcare (Erdogan, 2019). This meta-analysis included eight randomized controlled trials examining the use of serious games in nursing education. The analysis supported the effects of using serious games in nursing education. The game platforms used in the studies were games developed with different software and technologies. All included studies were conducted within the scope of theoretical lectures, followed by laboratory applications. In all studies, the results of serious game use were compared with those of the traditional education method. The sample sizes of the studies included in the meta-analysis varied. Therefore, the random-effects model was used to analyze the data. Despite the heterogeneity among studies, serious games positively affected nursing students' knowledge, skills, and self-confidence.

The effects of serious games on knowledge output were evaluated in seven studies included in the meta-analysis. Game-like simulation methods make the information more permanent (Del Blanco et al., 2017). Also, digital contextual games in nursing education effectively enhance knowledge, skills, motivation, critical thinking, and learning attitude (Hwang and Chang, 2020). In this meta-analysis, serious games were found to have a low to moderate effect on knowledge output. Thangavelu et al. (2022) demonstrated a significant effect of serious games on the knowledge output regarding the adequacy of nursing care. Lau et al. (2018) reported that digital resuscitation training was effective on knowledge scores. A meta-analysis examining the effect of serious games, computer-aided games, virtual simulation, and other simulation technologies on the learning outcomes of nursing students showed a significant effect of learning with simulation in terms of knowledge acquisition compared with traditional learning methods (Mulyadi et al., 2021). These findings aligned with previous studies. Maheu-Cadotte et al. (2021) reported no significant effect of serious games on knowledge scores, while Vermeir et al. (2020) reported a positive but small effect of gamification on cognitive processes.

The heterogeneity of the information output of the reviewed studies was high. The sample numbers in the included studies ranged between 36 and 122, and the heterogeneity values in meta-analyses were affected by large sample ranges. The differences in the measurement time of the knowledge score post-tests in the experimental and control groups, and the variability of the measurement tools in the studies in the meta-analysis might also be considered as a factor in terms of heterogeneity. In only one of the studies (Bayram and Caliskan, 2019), the knowledge scores were similar between the experimental and control groups. In other studies, the knowledge scores were higher in the serious play intervention groups. The meta-analysis was similar to the studies by Lau et al. (2018) and Vermeir et al. (2020), Mulyadi et al. (2021), and Thangavelu et al. (2022) in terms of heterogeneity. In the study by Dhivya et al. (2022), the heterogeneity was low.

The meta-analysis showed that the pooled effect size in forest plots for the knowledge outcome was 0.49, indicating that serious games had a low-to-moderate effect on increasing knowledge scores in nursing education. A literature review showed that the animations in digital learning games attracted students' attention and had an increasing effect on their cognitive load (Woo, 2014). The suitability of video games for short, intermittent play sessions, along with the ability of students to control their game time, contributes to an increase in the level of knowledge and learning experiences (Andersen et al., 2015). Cognitive skill sets in digital games, such as reading, interpretation, judgment, and visualization, enable players to grasp the meaning of images (Subrahmanyam and Renukarya, 2015). More research findings are needed to demonstrate that serious games are more effective on knowledge outcomes.

As a result of the meta-analysis, the effect sizes of studies without a debriefing session (AL-Mugheed et al., 2022; Bayram and Caliskan, 2019; Chang et al., 2021;) were found to be (Hedges' g = 0.429; Hedges' g = 0.194; Hedges' g = 0.689;) respectively, while the effect sizes of studies with comprehensive or partial debriefing (Farsi et al., 2021; Karaduman and Basak, 2023; LeFlore et al., 2012; Tan et al., 2017) were found to be (Hedges' g = −0.659; Hedges' g = −0.202; Hedges' g = 0.651, Hedges' g = 2.278) respectively (Fig. 2a). It is stated that comprehensive debriefing enhances the effectiveness of simulation-based training (Cheng et al., 2016). In the literature, it is stated that comprehensive debriefing in simulation applications improves knowledge results (Secheresse et al., 2021). Although the results found in the meta-analysis support the literature, more research findings are needed on this subject.

This meta-analysis included eight studies. When the effect sizes of all studies included in the meta-analysis were pooled, it was found that the serious/virtual game method was effective in teaching skills in nursing education and that this effect was moderate to large. In a meta-analysis conducted by Dhivya et al. (2022), serious games had a medium effect on skill teaching. In a meta-analysis conducted by Lau et al. (2018), digital learning was effective in developing the resuscitation skills of health professionals. A meta-analysis by Maheu-Cadotte et al. (2021), examining the effects of serious games in health professions education, reported that serious games had a low effect on skill development. In a systematic review conducted by Foronda et al. (2020), it was reported that the use of virtual simulation in nursing education had positive effects on skill outcomes.

An examination of the studies revealed that all skill assessments were performed using a skill checklist or valid measurement tools, and random assignments were applied to the intervention and control groups. This situation is critical in terms of presenting evidence-based

nursing practices.

Heterogeneity is an essential concept in meta-analysis and a determining factor in interpreting effect size. In this meta-analysis, the heterogeneity in terms of skill outcome was high, which was probably caused by the differences in the sample size of the included studies. However, the inclusion of only RCTs in the meta-analysis, the exclusion of studies that did not measure psychomotor skills, and the low-bias analysis of the studies might increase the specificity of the subject on which the meta-analysis focused. When the forest plots of the meta-analysis were examined, the fact that the effect size for skill output was moderate indicated that the use of serious games in nursing education increased the skill level of students. The fact that games could be played many times and outside the classroom at the appropriate place and time provided automatization in the implementation of skills (Müller and Mathews, 2013; Pront et al., 2018). On the contrary, games were useful in developing decision-making and reasoning skills (Johnsen et al., 2018). Another contribution of games was that the feedback provided during play was effective in experiencing the skills (Robb and Gerwick, 2013).

According to Jeffries (2005), measuring knowledge, skills, self-confidence, and satisfaction outcomes is essential in simulation applications in nursing education. As the serious games in the studies included in the meta-analysis contained virtual simulation elements, including the self-confidence outcome in the analysis was considered essential. Two studies (Karaduman and Basak, 2023; Tan et al., 2017) reported a moderate effect of serious games on self-confidence outcomes.

Previous studies with nursing students found that virtual patient simulations increased students' self-confidence (Ismailoglu and Zaybak, 2018; Ross and Carney, 2017). A systematic review by Labrague et al. (2019) showed that simulation increased the level of self-confidence compared with traditional education methods. Tan et al. (2017) examined the effectiveness of a serious game for blood transfusion and demonstrated that the level of self-confidence was higher, and a relationship between high knowledge level and increased self-confidence scores existed in this group. A meta-analysis examining the effect of different simulation techniques, including computer-based, video-supported, serious, and virtual games, reported that learning with simulation was moderately effective on students' self-confidence compared with traditional learning (Mulyadi et al., 2021). In the study by Foronda et al. (2020), it was stated that in most of the studies included in the review, virtual simulation increased self-confidence.

In 3 studies with participants from different grade levels (AL-Mugheed et al., 2022; Chang et al., 2021; Aebersold et al., 2018), homogeneity of the groups in terms of grade level was ensured because the participants were randomly assigned to the experimental and control groups. In the study of Chang et al. (2021), it was stated that there was no difference between pre-test knowledge scores according to age groups because the students were homogeneously distributed to the groups. In the meta-analysis, when the effect sizes were examined by grade level in terms of skill outcome, the individual effect sizes of the studies involving 1st graders were found to be moderate (Fig. 2b). In terms of knowledge outcome, the study conducted by Tan et al. (2017) with 2nd grade students was found to have the largest individual effect size (Fig. 2a). Despite these results, since the basic skills examined in the studies were different and showed heterogeneity, interpreting the study results at the class level may cause bias. In order to provide this evidence, further analyses in which the same skills are examined and comparisons are made between grades are needed.

When the individual effect sizes of the studies were examined according to game type, it was found that the highest effect size in the knowledge and confidence outcomes was observed in the study by Tan et al. (2017), which investigated the effect of a serious game played via a mobile tablet (Fig. 2a and Fig. 2c). The highest effect size on skill outcomes was observed in the study by AL-Mugheed et al. (2022), which examined the effect of a virtual reality application played on a mobile phone (Fig. 2b). No studies comparing the effectiveness of game types played in virtual environments were encountered in the literature. Participants in games played on mobile phones may have achieved higher skill outcomes because they can behave more freely individually and can play the game whenever they want, regardless of time and place. On the other hand, instant feedback and analysis sessions in games played via mobile tablets in the laboratory or simulation center can improve participants' knowledge, confidence, and satisfaction outcomes. However, further research is needed to validate and discuss the meaningfulness of the results obtained from the meta-analysis.

In this meta-analysis, the heterogeneity was high due to the small number of studies examining self-confidence outcomes and the small total sample size. Previous studies demonstrated high heterogeneity in self-confidence outcomes (Mulyadi et al., 2021).

4.1. Strengths and limitations

One strength of this study could be the inclusion of randomized controlled trials involving only undergraduate nursing students in the meta-analysis. The integration of effect sizes is feasible with two or more studies, but for more accurate results, it is recommended to include more than five studies. In this study, the number of studies was sufficient to determine the effect size by system, but there were too few studies addressing such as self-confidence, satisfaction, perception, attitude, anxiety some individual-related factors. More research is needed to strengthen the evidence.

5. Conclusions

This study reported a low-to-moderate effect of serious games on knowledge and a moderate effect of serious games on skills and self-confidence outcomes in nursing education. The meta-analysis results that serious games were effective education methods in teaching the skills that should be acquired for clinical practice in undergraduate nursing education. Integrating computer-aided technological education methods and game-based educational tools into nursing education is increasingly important for nursing education to benefit from the developments brought by the modern age. However, these innovative technologies should be used with traditional education methods in a hybrid manner. They should not replace the clinical field practices of nursing education but should be included in the curriculum to support them.

CRediT authorship contribution statement

Burcu Demircan: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yasemin Kıyak:** Writing – review & editing, Resources, Methodology, Investigation, Data curation. **Hatice Kaya:** Writing – review & editing, Supervision, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the revision of this work the author(s) used [ChatGPT-3.5/ artificial intelligence tool] in order to [only language editing]. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

Authors declare that there is no any financial support or relationships that may pose conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.nedt.2024.106330.

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