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Subin Park[1] MSN; Hui Ju Shin[1, 2] BSN; Hyoeun Kwak[1] MSN; Hyun Joo Lee[3, 4] PhD

[1]College of Nursing, Yonsei University, Seoul, Korea Seoul KR
[2]Severance Hospital, Yonsei University Health System, Seoul, Republic of Korea Seoul KR
[3]Mo-Im Kim Nursing Research Institute, Yonsei University College of Nursing, Seoul, Republic of Korea Seoul KR
[4]Yonsei Evidence-Based Nursing Centre of Korea: A Joanna Briggs Institute Affiliated Group, Seoul, Republic of Korea Seoul KR

**Corresponding Author:**
Hyun Joo Lee PhD
Mo-Im Kim Nursing Research Institute, Yonsei University College of Nursing, Seoul, Republic of Korea
Seodaemun-gu, Seoul, Republic of Korea
Yonsei University , 50-1 , Yonsei-ro
Seoul
KR

## *Abstract*

**Background:** The utilization of immersive technology for simulation-based learning in the realm of nursing has grown significantly over the years. Immersive technology can reduce the limitation of resources which are needed to immerse the students in simulation. Also, immersive technology enables students to access the clinical environments without threatening patient safety and allows instructors to interact with students actively. Despite the advantages of immersive technology, there are claims suggesting that immersive technology-based teaching methods may not be notably effective compared to traditional teaching methods. Therefore, verifying the effectiveness of immersive technology in simulation learning is necessary for continuing the future educational programs.

**Objective:** The objective of this study was to systematically review the contents of immersive technology-based education for undergraduate nursing students and evaluate the effectiveness of immersive technology over traditional teaching methods

**Methods:** The methodology of this study adhered to the guidelines outlined in the Cochrane Handbook for Systematic Reviews of Interventions. Randomized controlled trials and quasi-experimental studies in English or Korean were searched across four databases. The quality assessment was assessed using Version 2 of the Cochrane risk of bias tool (RoB 2) and the risk of bias assessment tool for non-randomized studies (ROBANS). Meta-analysis was conducted utilizing RevMan 5.4 software, and the main outcomes were based on New World Kirkpatrick Model(NKWM).

**Results:** A total of 23 studies were found. 4 studies used augmented reality (AR) and 19 used virtual reality (VR), covering various nursing scenarios in settings like disaster training, resuscitation, health assessments, and home healthcare. Approximately 70% of scenarios involved virtual patients. Based on Kirkpatrick's evaluation model, the main outcome variables were satisfaction, anxiety, knowledge, confidence, self-efficacy, performance, and clinical reasoning, which were included in Levels 1 to 3. The meta-analysis revealed that immersive technology-based nursing education has demonstrated effectiveness across various domains, including knowledge attainment (standard mean difference(SMD)=0.63, 95% confidence interval(CI)= 0.30-0.97, P=.00002, I2=91%), self-efficacy (SMD=0.86, 95% CI= 0.42-1.31; P=0.0001, I2=63%), and performance (SMD=1.41, 95% CI= 0.36-2.46; P=.0008, I2=92%), while confidence (SMD=-0.06, 95% CI= -1.68-1.57; P=0.95, I2=98%) did not show significant results.

**Conclusions:** These findings support the effectiveness of immersive technology-based education for undergraduate nursing students, despite heterogeneity in methods and interventions. We suggest the long-term cohort studies which evaluate the effects of immersive technology-based nursing education on the NWKM Level 4.

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**Conclusions:** These findings support the effectiveness of immersive technology-based education for undergraduate nursing students, despite heterogeneity in methods and interventions. We suggest the long-term cohort studies which evaluate the effects of immersive technology-based nursing education on the NWKM Level 4.


**Keywords:** Education, Nursing; Immersive Technology; Students; Nursing; Systematic Review

## Introduction

Immersive technology is widely recognized to improve learning in nursing education [1,2]. The idea of immersive technology emerged six decades ago with the human-computer prototype known as the 'Man-Machine Graphical Communication System' [3]. Immersive technology is derived from the reality-virtuality continuum concept and encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) altogether [2]. Extended reality (XR), an umbrella term that includes all three technologies, is recognized as an immersive technology [4]. The degree of immersion is related to the stimulated senses, interactions, and similarities between reality and virtuality [5]. Through immersive technology, individuals can embody virtual experiences in simulated environments with low to high levels of immersion [6].

A significant goal of nursing education is the transfer of theoretical knowledge to clinical practice [7]. However, limited clinical resources impact students' opportunities to gain hands-on experience with patients, and the lack of long-term clinical practice over the long period may pose a risk to patient safety [8,9]. Therefore, nursing educators should provide students with sufficient alternative clinical experiences [8]. To ensure the quality of nursing education in clinical practice, educators have integrated various educational strategies, including simulations [10]. Various clinical simulation methods have been developed [11]. Especially in the nursing field, there is a growing interest in using immersive technology as an effective educational tool for simulation-based programs to enhance students' knowledge and skill acquisition [4,12].

Immersive technology reduces the limitations of the resources required for 2D simulation-based learning and overcomes these barriers [13]. Education programs adapted to immersive technology enable students to access clinical practice with ease and hone their skills within a secure setting, minimizing risks to patient safety [13, 14]. According to the study conducted by Foronda et al. (2014), 98% of the participants expressed a preference for incorporating virtual learning environments [15]. There have been efforts to further the leverage of immersive technology, especially with the increased significance of remote classes due to the outbreak of the coronavirus infectious disease-19 [16, 17]. Additionally, because immersive technology improves the interaction between students and instructors by facilitating discussions, it is frequently used in simulation-based learning [18]. Student-instructor interaction helps derive successful outcomes when properly supported by high-fidelity simulations [19].

The Kirkpatrick Model, developed by Donald L. Kirkpatrick in 1959 and expanded in 1967, is a widely used framework for evaluating the effectiveness of educational programs. This model categorizes program outcomes into four levels [20]. Level 1 encompasses participants' reactions, assessing how favorable, engaging, and relevant they find the training to be in relation to their jobs. Level 2 includes the results of learning; at this level, the focus is on the knowledge, skills, attitude, confidence, and commitment acquired by learners as a result of training. Level 3 evaluation is related to changes in the participants' behavior based on the simulation experience. Level 4 is the final outcome evaluation, which indicates the actual changes in the output or results due to the training. In 2010, the 'New World Kirkpatrick Model' (NWKM) emerged, presenting a framework with four levels of evaluation that is more effectively applicable to today's changing circumstances [20]. It modifies the direction of the result levels in reverse, in the order of levels 4 to 1 [20,21]. The NWKM proposes planning the eventual program outcomes in the planning stage. Some outcomes have been added to each level of evaluation, and some parts of the definition have been revised. Both quantitative and qualitative methods can be used to evaluate each level, and this model has been widely used to evaluate the outcomes of education programs in the nursing field [22-24].

While there are evident advantages to using immersive technology in nursing education, it is important to note that there are claims suggesting that it may not be notably effective compared to traditional teaching methods [10,25-27]. In addition, many studies have verified the effectiveness of VR methods in nursing education [10, 28-29], however, there remains a shortage of studies that comprehensively assess the effectiveness of immersive technology encompassing all concepts of VR, AR, MR, and XR. Therefore, this study aimed to systematically review the contents of immersive technology-based education programs for undergraduate nursing students, including various concepts of immersive technology, and evaluate the outcomes of education programs based on Kirkpatrick's model by meta-analysis.

## Methods

This study adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. The study protocol was preregistered in the International Prospective Register of Systematic Reviews (PROSPERO) with the registration number CRD42023400085.

### Eligibility criteria

The eligibility criteria were established with consideration for population, intervention, comparison, and outcome criteria. Target population was undergraduate nursing students. The search for studies included randomized controlled trials (RCTs) and quasi-experimental studies utilized virtual reality (VR), augmented reality (AR), extended reality (XR), and mixed reality (MR) technologies. Regarding the scope of VR technology, the search specifically focused on studies that utilized Head-Mounted Devices(HMD) whereas other immersive technologies such as AR, XR, and MR encompassed all devices such as smartphones and smart glasses [5]. The outcome variables were not restricted to the search and were categorized according to the New World Kirkpatrick Model [20]. Studies that were not published in either English or Korean, as well as ongoing research, such as pilot studies, were excluded.

### Search strategy

A thorough search was conducted across the PubMed, CINAHL, Embase, and Web of Science databases. The search terms were selected judiciously, adhering to the principles of the Medical Subject Headings (MeSH), with specific terms customized for each database. Additionally, consultation with a librarian at the medical library informed and refined the search strategy. The exploration was conducted in January 2023. The search records were imported into the reference management tool Endnote, and in parallel into Covidence, a specialized program for systematic reviews. Following the application of Covidence's artificial intelligence (AI) function to automatically identify and remove duplicate studies, manual confirmation was performed. After eliminating duplicates, the remaining studies underwent eligibility screening by two independent reviewers (PSB and SHJ) according to the predefined inclusion and exclusion criteria. In cases of discrepancies between the two reviewers, a third reviewer (KHE) was consulted to reach a consensus. The initial screening process involved the assessment of titles and abstracts for relevance. Subsequently, full-text screening was performed, and the rationale for exclusion were documented in the PRISMA flowchart.

### Quality assessment

The quality assessment of all randomized studies was appraised based on the second version of the Cochrane risk of bias tool (RoB 2). RoB 2 consists of five key domains that evaluate potential biases in study design and conduct. These domains covered related to the randomization process, intended intervention, absence of outcome data, and selective report of results. The individual domains were assessed for their potential influence on the validity of the findings. The quality assessment of non-RCT studies were based on the Risk of Bias Assessment tool for Non-randomized Studies (RoBANS). The domains encompass issues such as bias stemming from participant selection, confounding variables, measurement, blinding, incomplete outcome data, and selective report of results. At least two reviewers independently assessed the quality of the included studies.

### Data extraction

An exclusive data extraction template was utilized to collect pertinent details from each study, encompassing author, publication year, country, research design, participants, and sample size. Regarding immersive technology interventions, the extracted items encompassed the type of technology, content characteristics, length and duration of intervention, facilitator details, presence of prebriefing and debriefing sessions, scenarios, and the VR content development company. For outcome variables, the extracted information included measurement timing, evaluated variables, measurement tools, and classification based on Kirkpatrick's evaluation model, and the mean and standard deviation (SD) values were extracted for subsequent meta-analysis.

### Data analysis

Reviewer Manager 5.4 (Revman 5.4) software was used to synthesize the data. The overall effect size was calculated using the Standardized Mean Difference (SMD)along with a 95% confidence interval (95% CI), as the studies used different measurements for each outcome. For the pre-post-test, if changes in the measurement variables were not reported, the correlation between the two covariances was assumed to be 0.5 [30], and the changes and measurement variances of the variables were reported accordingly. The effect size was classified according to Cohen as small (0.2), medium (0.5), large (0.8), or very large (1.2) based on Cohen. To analyze the overall effect, Z-statistics were applied at a significance level of $P < 0.05$. Heterogeneity was estimated using Higgins' I2 statistic, which provided insight into the degree of variation among the included studies. Heterogeneity can be interpreted as non-observed (0%), low (0%–25%), moderate (25%–50%), or high (> 50%) [31]. The results of the meta-analysis are presented as tables and forest plots.

## Results

### Study selection

Figure 1 shows the process of study selection based on PRISMA flow. A total of 3,204 studies were identified by searching the four databases. The artificial intelligence(AI) function of Covidence automatically removed 1534 duplicates. In addition, 18 studies were manually identified as duplicates. Of the remaining 1,652 papers, 1,546 were excluded after a thorough review of titles and abstracts. The remaining 106 papers were full-text screened, and 83 papers were excluded for the following reasons: not related to immersive technology (e.g., VR not using HMD) (n=46), incorrect study design (n=22), unavailable full text (n=10), not including undergraduate nursing students (n=2), not in Korean or English (n=1), and thesis or dissertation (n=2). Finally, 23 studies were selected for meta-analysis.

### Study Characteristics

Table 1 presents the study characteristics. The research was carried out in 8 different countries: China (1 of 23), Finland (1 of 23), Norway (2 of 23), South Korea (6 of 23), Spain (2 of 23), Taiwan (5 of 23), Turkey (2 of 23), and the United States (4 of 23). The number of participants ranged from a minimum of 33 to a maximum of 289. Among the 23 studies, 21 were conducted with nursing students as the primary participants, whereas the remaining two specifically targeted both medical and nursing students. Six studies were randomized controlled trials, and 17 were quasi-experimental studies. Among the quasi-experimental studies, one employed a single-group pretest-posttest design. Additionally, 3 trials utilized a 3-arm design, while the remaining 13 studies adopted a 2-arm design. The experimental group received VR or AR education, whereas the control group received traditional education.

### Intervention characteristics

Four studies utilized AR, whereas the remaining 19 employed VR in their educational programs. The intervention scenarios covered a wide range of nursing situations, including disaster training, resuscitation, nursing education, health assessments, and home healthcare nursing. The virtual locations for the intervention scenarios varied, encompassing settings such as the patient’s home and clinical environments, including general wards, emergency room (ER), intensive care units (ICUs), neonatal intensive care units (NICUs), delivery rooms, angiography rooms, operating rooms (ORs), and isolation units. Notably, approximately 70% of the scenarios represented virtual patients. The length of the scenarios ranged from 8 to 50 min, with some studies not specifying a time limit or providing explicit information regarding the scenario length. Among the studies, 43% (10 of 23) included both prebriefing and debriefing sessions, whereas 17% (4 of 23) did not incorporate either prebriefing or debriefing. Regarding the equipment required for interventions, studies have utilized AR-adopted devices such as smartphones or tablets with cameras and screens to augment the fidelity of objects. VR interventions utilize a HMD alone or in conjunction with a haptic device.

**Figure 1. PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) flow diagram of the study selection**

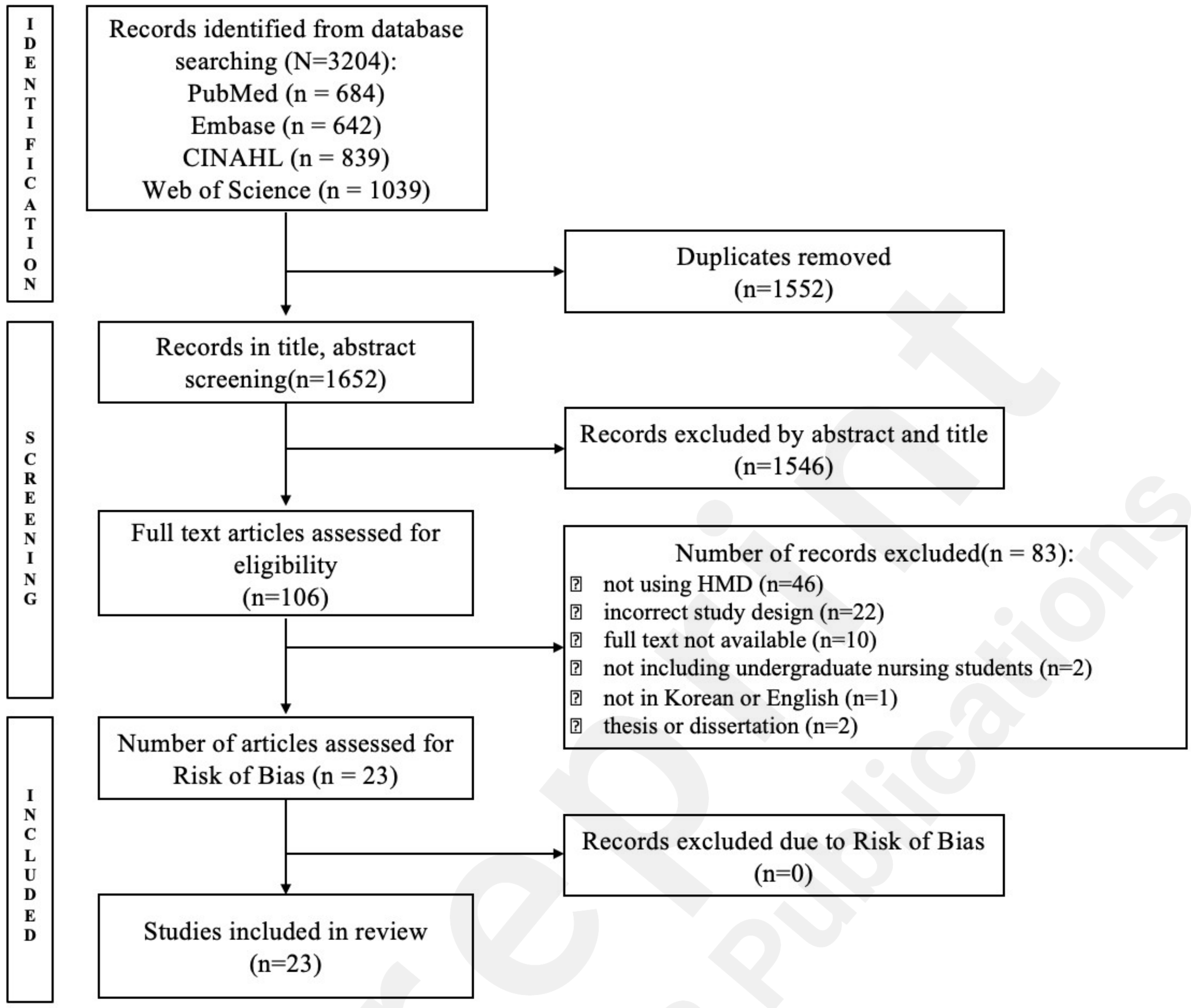


Table 1. General Characteristics of Included Studies

| Author(year) | Country | Type of Immersive Technology | Study Design | Participants | Sample Size (Total) |
|---|---|---|---|---|---|
| Ahn et al (2021) | South Korea | VR | Quasi-Experimental | Third year nursing students | 84 |
| Berg, H., & Steinsbekk, A. (2020) | Norway | VR | RCT | First year medical/nursing students | 289 |
| Berg, H., & Steinsbekk, A. (2021) | Norway | VR | RCT | First year medical/nursing students | 289 |
| Chang et al (2022) | Taiwan | VR | Quasi-Experimental | Nursing students from a single nursing college | 64 |
| Chao et al (2021) | Taiwan | VR | RCT | Nursing students | 45 |
| Chen et al (2021) | Taiwan | VR | Quasi-Experimental | Third year nursing students | 79 |
| Chen, P. J., & Liou, W. K. (2023) | Taiwan | AR | RCT | Fourth year nursing students | 95 |
| Dang et al (2021) | USA | VR | Quasi-Experimental | Prelicensure, baccalaureate nursing students in their first medical-surgical course | 160 |
| Havola et al (2021) | Finland | VR | Quasi-Experimental | Single university graduating nursing students | 40 |
| Herbert et al (2021) | USA | AR | Quasi-Experimental | Second-semester junior nursing students | 33 |
| Jung, A. R., & Park, E. A. (2022) | South Korea | VR | Quasi-Experimental | Second, third, fourth year nursing students | 60 |
| Kurt, Y., & Öztürk, H. (2021) | Turkey | AR | Quasi-Experimental | First year nursing students | 122 |
| Lee, H., & Han, J. W. (2022) | South Korea | VR | Quasi-Experimental | Fourth year nursing students | 60 |
| Rodríguez-Abad et al (2022) | Spain | AR | Quasi-Experimental | Second year nursing students | 137 |
| Sen et al (2022) | Turkey | VR | Quasi-Experimental | Second year nursing students taking the operating room nursing course | 40 |
| Shujuan et al (2022) | China | VR | RCT | Nursing students in second year of a tertiary program, registered for the disaster nursing course | 101 |
| Silva et al (2023) | Spain | VR | RCT | First year students from the Faculty of Nursing | 100 |
| Smith et al (2018) | USA | VR | Quasi-Experimental | Senior baccalaureate degree nursing students, recruited from four different Midwest university campuses | 172 |
| Smith et al (2021) | USA | VR | Quasi-Experimental | Senior nursing students in the final semester of a baccalaureate nursing program | 121 |
| Wu et al (2022) | Taiwan | VR | Quasi-Experimental | Third year nursing students from single university, 9 pediatric classes | 105 |
| Yang, S. Y., & Oh, Y. H. (2022) | South Korea | VR | Quasi-Experimental | Prelicensure nursing students | 83 |
| Yu et al (2021) | South Korea | VR | Quasi-Experimental | Senior nursing students | 50 |
| Yu, M., & Yang, M. R. (2022) | South Korea | VR | Quasi-Experimental | Third and fourth year nursing students | 50 |

## Types of outcome variables

The outcome variables of each study were classified using the New World Kirkpatrick Model [20] (Table 2). The outcomes were satisfaction (n=11), usability (n=3), sense of realism (n=1), anxiety (n=1), knowledge (n=20), confidence (n=6), self-efficacy (n=5), performance (n=13), attitude (n=2), motivation(n=4), critical thinking (n=1), and clinical reasoning (n=2). These outcomes were categorized according to the New World Kirkpatrick Model levels 1 to 3, and there was no outcome variable corresponding to level 4.

## Risk of Bias

Figure 2 shows the results of Risk of bias assessment. Version 2 of the Cochrane Risk of Bias tool (RoB 2) was used to appraise 6 randomized controlled studies. Among these, four studies confirmed all components to have low risk. In 2 studies, missing outcome data uncertainty was observed in one study, and uncertainty regarding deviation from the intended intervention was assessed in another study. The Risk of Bias Assessment tool for Non-randomized Studies (RoBANS) was utilized to assess the quality of the 17 non-RCT studies. Among these, 15 studies had a high risk of bias in the measurement of the intervention. They used self-reported methods to assess outcome variables. In the incomplete outcome data category, 15 studies reported a low dropout rate, making them suitable for classification under a low risk of bias. Two studies were categorized as having an unclear risk of bias. A quasi-experimental study was re-evaluated and discussed to resolve discrepancies in quality assessment, ultimately reaching a consensus.

Table 2. Intervention Characteristics of Included Studies

| Author (year) | Intervention | Equipment | Comparison | Scenario(setting) | Simulation Learning Method (Group/ individual), | Length (min) | Featuring Whole Patients | Instructor | Pre/ Debriefing | Outcomes* |
|---|---|---|---|---|---|---|---|---|---|---|
| Ahn et al (2021) | HVRS(Home-visits virtual reality simulation) program: Includes community nursing curriculum application, core skills, health education, etc. | PC HMD controller (haptic device) | Traditional education | Visiting nurse (patient's home) | Individual | 8-10 | O | NR | O/X | Knowledge(2,+) Performance(2,+) confidence(2,+) self-efficacy(2,+) |
| Berg, H., & Steinsbekk, A. (2020) | The VirSam ABCDE application | HMD haptic device | Self-learning with equipment | X(X) | Individual | no time limit | O | NR | X/X | Knowledge(2,-) Satisfaction(1,NR) Usability(1,+) |
| Berg, H., & Steinsbekk, A. (2021) | The VirSam ABCDE application | HMD haptic device | Self-learning with equipment | X(X) | Group | no time limit | O | NR | X/X | Knowledge(2,-) Satisfaction(1,NR) Usability(1,+) |
| Chang et al (2022) | The SVVR-based childbirth learning system: Childbirth education | VR BOX (Virtual reality glasses) mobile device | Traditional video approach | Childbirth (Delivery room) | Individual | X | O | NR | X/X | Knowledge(2,+) Motivation(2,+) Attitude(2,-) Critical thinking(2,-) Satisfaction(1,+) |
| Chao et al (2021) | Immersive 3D interactive video program via VIVEPAPER: observe NG tube feeding, the program includes quizzes and information on physiology and anatomy relating to NG tube feeding | HMD (HTC vive) | Traditional education (watching NG tube feeding video) | NG tube feeding (clinical ward) | Individual | 10-20 | X | Researcher | O/X | Knowledge(2,-) Confidence(2,-) Satisfaction(1,+) |
| Chen et al (2021) | 3D holograms | Windows Mixed Reality Helmet VR remote control | Traditional education | Health assessment and practice(x) | Individual | X | O | College lecturer | O/X | Knowledge(2,+) Performance (2,+) |
| Chen, P. J., & | AR pediatric first aid training and evaluation | Mannequin screen | Mannequin | First aid for choking and CPR(X) | Individual | 30 | O | NR | O/O | Knowledge(2,+) Performa |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Liou, W. K. (2023) | system(AR-PFAES) : includes APGAR score, aspiration, saturation monitoring, L-tube insertion, chest compression, intubation, medication) | | | | | | | | | nce(2,+)<br>Confidence(2,+) |
| Dang et al (2021) | Multi-site evaluation of observer roles | Virtual reality goggle | Traditional education (active participants/observer/ AV observer) | Patient complains lower leg pain after a surgical procedure(X) | Group | X | X | NR | O/O | Knowledge(2,-)<br>Presence(1,+)<br>Usability(1, NR) |
| Havola et al (2021) | VR simulation: assessing a patient suffering from chest pain | VR headset | X | Resuscitation (beside chest pain patient, ICU) | Individual | 16 | O | NR | O/X | Clinical reasoning (3,+) |
| Herber et al (2021) | AR app on Heart Failure: anatomy and physiology of the heart | Smartphone | Traditional education (video lecture) | X(X) | Individual | X | X | NR | O/X | Knowledge(2,-)<br>Satisfaction(1,-) |
| Jung, A. R., & Park, E. A. (2022) | Head mounted display (HMD)based virtual reality(VR) nursing education program(VRP): see Chemoport insertion surgery process in 360 degrees | HMD | Self-learning | A chemoport insertion surgery nursing (angiography room) | Individual | X | O | Researcher | O/O | Knowledge(2,+)<br>Attitude(2,+)<br>Satisfaction(1,+)<br>Motivation(2,-) |
| Kurt, Y., & Öztürk, H. (2021) | Mobile Augmented Reality: SC, IM, and IV injections | Smartphone | Traditional education | X(X) | Individual | X | X | NR | X/O | Knowledge (2,+)<br>Performance (2,+) |
| Lee, H., & Han, J. W. (2022) | Mechanical ventilation VR nursing program: Scenario 1 High pressure alarm 2 Low exhaled volume alarm 3 High respiration rate alarm | HMD(Oculus goggles) | Traditional education (video lecture) | Troubleshooting for ventilator alarms (ICU) | Individual | 15 | O | Researcher | O/O | Knowledge (2,-)<br>Self-efficacy(2,+)<br>Performance (2,+)<br>Satisfaction(1,+) |
| Rodríguez-Abad et al (2022) | AR in learning about leg ulcer care: knowledge and skills about leg ulcer care | Smartphones or tablets | Traditional education | X(X) | Individual | 15 | X | NR | X/O | Performance(2,+)<br>Motivation(2,+) |
| Sen et al. (2022 | Mobile virtual reality education program: surgical aseptic skills (washing hands, wearing sterile gloves, opening sterile packages, wearing the surgical gown, etc) | VR glasses smartphones | Traditional education | Surgical aseptic skills(OR) | Individual | 30 | NR | NR | X/X | Knowledge (2,+)<br>Performance (2,+)<br>Confidence(2,+) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Shujuan et al (2022) | Disaster nursing VR training program: (earthquake and fire), triage, wound dressing, fixation, hemostasis, debridement, cardiopulmonary resuscitation, tracheal intubation, transportation, decontamination, and supportive psychological care | HMD | Traditional education and low fidelity simulation | Two disaster scenes and disaster nursing skills(disaster scenes of earthquake or fire) | Individual | 10-25 | O | NR | O/X | Knowledge(2,+) Confidence(2,+) Performance(2,+) |
| Silva et al (2023) | VR simulation for development communications skills | Computer VR goggles Head-phones | Traditional workshop | Communication Skills performance (x) | Group | x | X | NR | O/O | Knowledge(2,+) Performance(2,+) |
| Smith et al (2018) | Disaster nursing skill of decontamination: Donning personal protective equipment and performing actual skill of decontamination | PC HMD controller | Traditional education | Decontamination in disaster(ER) | Individual | 10 | X | NR | O/X | Knowledge(2,-) Performance(2,-) Satisfaction(1,NR) |
| Smith et al (2021) | VRS in disaster training: donning PPE, cutting and removing decontaminated clothing, washing different areas of the patient in the proper order and removal of contaminated PPE in the proper order | HMD, motion-tracked head and hand controllers | Low-fidelity simulation (static mannequin) | decontamination in disaster (X) | Individual | 10 | O | NR | O/X | Performance(2,-) Satisfaction(1,-) Self-efficacy(2,-) |
| Wu et al (2022) | VRS(virtual reality program: administer oxygen ensure safety(falls) vital sign, and mental family education wash hands nursing record | computers, Oculus Rift S(LCD HMD) | Traditional education | Pediatric seizure management(pediatric ward) | Individual | 10-15 | O | NR | O/O | Knowledge(2,+) |
| Yang, S. Y., & Oh, Y. H. (2022) | VR Neonatal resuscitation gamification program: APGAR score, aspiration, saturation monitoring, L-tube insertion, chest compression, intubation, medication | HMD (Oculus Rift), HMD controller | Traditional education | Neonatal resuscitation (NICU) | Individual | 50 | O | NR | O/O | Knowledge(2,+) Performance(2,-) Clinical reasoning (3,+) Confidence(2,+) Motivation(2,+) Anxiety(+) |
| Yu et al (2021) | High-risk neonatal infection control (HirNIC) VR simulation | HMD hand controllers | Traditional education(Routine NICU practice) | Basic nursing situations related to infection control(NICU) | Individual | 40 | O | Teacher | O/O | Knowledge(2,-) Self-efficacy(2,+) Satisfaction(1,+) |

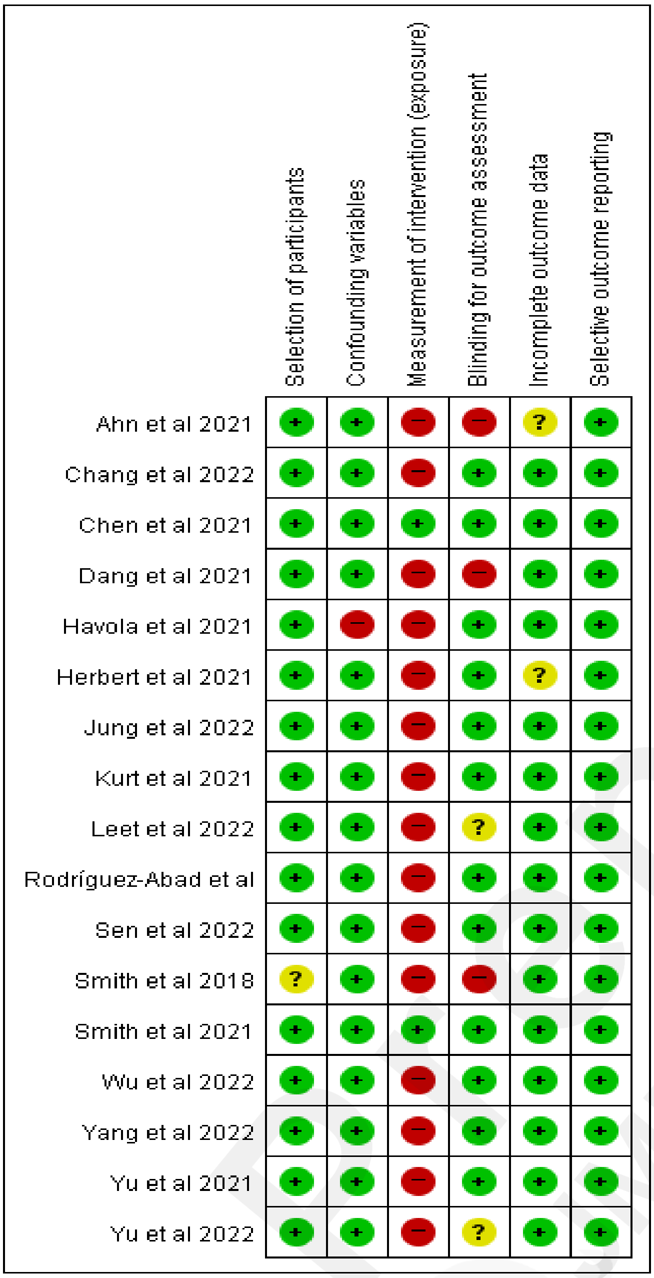
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Yu, M., & Yang, M. R. (2022) | Virtual reality infection control simulation (VRICS) program: Donning PPE, Respiratory Care(Patients status check and nasal-oral suction care), Dogging PPE | HMD, leap motion controller | No intervetion | Infection control;donning and doffing PPE,providing respiratory care for pediatric patients with COVID-19 (isolation unit with negative pressure system) | Individual | 15 | O | NR | O/O | Knowledge(2+) Performance(2,+) Self-efficacy(2,+) Presence(1,-) Satisfaction(1,-) |

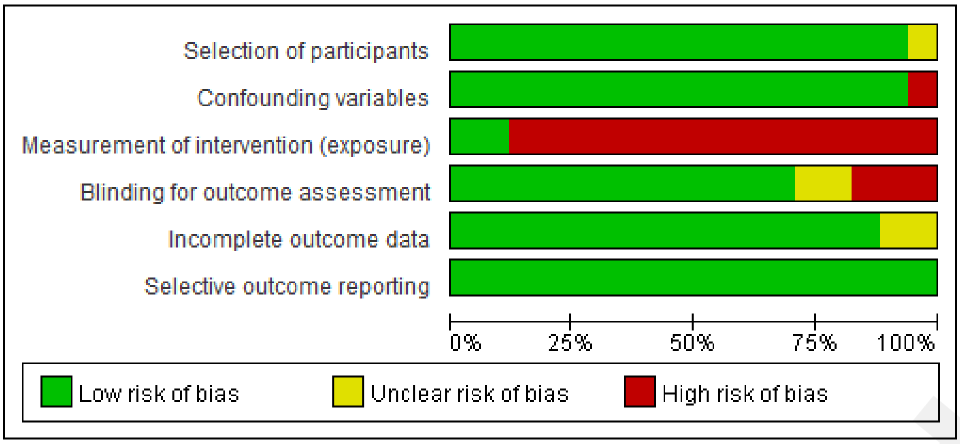
* Outcomes: Variable(Level of Kirkpatrick model, Effectiveness compared to comparison group)
** NR : Not reported

**Figure2. Risk of Bias summary**

**Figure2a. Risk of Bias summary of Randomized controlled Trial studies (RCTs)**

## Figure2b. Risk of Bias summary of Quasi-experimental studies






## Meta-analysis findings

### *Effects of immersive technology-based education on students' knowledge attainment*

Sixteen studies involving 870 students were analyzed to evaluate the effects of immersive technology-based education on students' knowledge attainment. The findings revealed that compared to control conditions, the interventions for the experimental group significantly enhanced students' knowledge with a medium effect size (Standardized Mean Difference [SMD]=0.63, 95% Confidence Interval [CI]: 0.30-0.97, $P$<.001). The heterogeneity test showed a high level of heterogeneity across the studies ($I^2$ =91%, $P$<.001) (Figure 3a).

### *Effects of immersive technology-based education on students' confidence*

Four studies involving 164 students were analyzed to evaluate the effects of immersive technology-based education on students' confidence. The findings revealed that immersive technology-based education showed no statistical difference compared to control conditions (SMD=-0.06, 95% 95% CI: -1.68-1.57, $P$=.95). The heterogeneity test showed a high level of heterogeneity across the studies ($I^2$ =98%, $P$<.001) (Figure 3b).

### *Effects of immersive technology-based education on students' self-efficacy*

Four studies involving 120 students were analyzed to evaluate the effects of immersive technology-based education on students' self-efficacy. The findings revealed that compared to control conditions, the interventions significantly enhanced students' self-efficacy with a large effect size (SMD=0.86, 95%CI: 0.42-1.31, P<.001). The heterogeneity test showed a high level of heterogeneity across the studies ($I^2$ =63%, $P$=.04) (Figure 3c).

### *Effects of immersive technology-based education on students' performance*

Three studies involving 114 students were analyzed to evaluate the effects of immersive technology-based education on student performance. The findings revealed that compared to control conditions, the interventions significantly enhanced students' performance with a large effect size (SMD=1.41, 95% CI: 0.36-2.46, P<.001). The heterogeneity test showed a high level of heterogeneity across the studies ($I^2$ =92%, $P$<.001) (Figure 3d).

**Figure 3. Forest plot of meta-analysis**

**Figure3a. Meta-analysis of effects of immersive technology education on students' knowledge acquisition**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn et al 2021 | 3.32 | 3.72 | 44 | 0.45 | 3.23 | 40 | 6.3% | 0.81 [0.37, 1.26] |
| Berg et al 2020 | 6.3 | 1.5 | 149 | 6.4 | 1.4 | 140 | 6.8% | -0.07 [-0.30, 0.16] |
| Berg et al 2021 | 6.3 | 1.4 | 146 | 6.2 | 1.4 | 143 | 6.8% | 0.07 [-0.16, 0.30] |
| Chao et al 2021 | 6.05 | 2.27 | 22 | 6.13 | 2.45 | 23 | 5.8% | -0.03 [-0.62, 0.55] |
| Chen et al 2021 | 42.1 | 8.634 | 40 | 35.11 | 9.74 | 39 | 6.2% | 0.75 [0.30, 1.21] |
| Chen et al 2023 | 10.93 | 1.015 | 46 | 10.04 | 1.44 | 49 | 6.4% | 0.70 [0.29, 1.12] |
| Dang et al 2021 | 0.32 | 2.252 | 51 | -0.09 | 2.68 | 60 | 6.5% | 0.16 [-0.21, 0.54] |
| Jung et al 2022 | 1.6 | 1.255 | 30 | -0.33 | 1.61 | 30 | 5.9% | 1.32 [0.76, 1.88] |
| Lee et al 2022 | 0.8 | 1.482 | 30 | 1 | 1.63 | 30 | 6.1% | -0.13 [-0.63, 0.38] |
| Shujuan et al 2022 | 54.4 | 10.857 | 49 | 47.5 | 9.07 | 52 | 6.4% | 0.69 [0.28, 1.09] |
| Silva et al 2023 | 1.77 | 0.723 | 50 | 0.95 | 1.23 | 50 | 6.4% | 0.81 [0.40, 1.21] |
| Smith et al 2018 | 7.47 | 0.29 | 59 | 6.69 | 0.3 | 58 | 6.1% | 2.63 [2.13, 3.13] |
| Wu et al 2022 | 2.58 | 1.568 | 53 | 1.62 | 4.22 | 54 | 6.5% | 0.30 [-0.08, 0.68] |
| Yang et al 2022 | 5.48 | 3.81 | 29 | 1.04 | 1.8 | 52 | 6.0% | 1.63 [1.11, 2.16] |
| Yu et al 2021 | 0.55 | 2.218 | 25 | 1.24 | 2.88 | 25 | 5.9% | -0.26 [-0.82, 0.29] |
| Yu et al 2022 | 2.08 | 1.401 | 25 | 0.32 | 2.31 | 25 | 5.8% | 0.91 [0.32, 1.49] |
| **Total (95% CI)** | | | **848** | | | **870** | **100.0%** | **0.63 [0.30, 0.97]** |

Heterogeneity: $Tau^2 = 0.41$; $Chi^2 = 161.02$, df = 15 ($P < 0.00001$); $I^2 = 91\%$
Test for overall effect: Z = 3.72 (P = 0.0002)

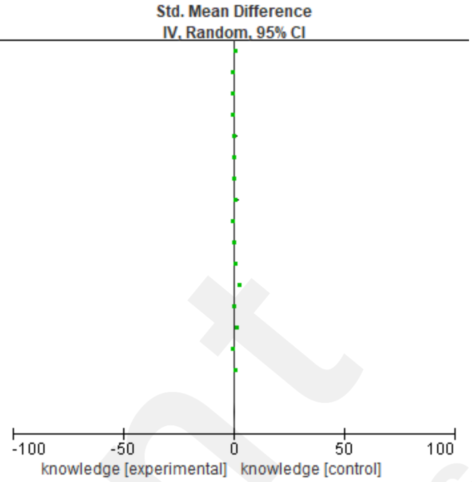



**Figure3b. Meta-analysis of effects of immersive technology education on students' confidence**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn et al 2021 | 1.64 | 1.77 | 44 | 0.29 | 1.77 | 40 | 25.1% | 0.76 [0.31, 1.20] |
| Chao et al 2021 | 8 | 3.745 | 22 | 7.48 | 3.54 | 23 | 24.8% | 0.14 [-0.44, 0.73] |
| Chen et al 2023 | 52.11 | 5.794 | 46 | 42.27 | 8.49 | 49 | 25.1% | 1.34 [0.89, 1.78] |
| Shujuan et al 2022 | 2.4 | 1.253 | 49 | 10.3 | 4.26 | 52 | 25.0% | -2.47 [-2.99, -1.94] |
| **Total (95% CI)** | | | **161** | | | **164** | **100.0%** | **-0.06 [-1.68, 1.57]** |

Heterogeneity: $Tau^2 = 2.70$; $Chi^2 = 130.53$, df = 3 ($P < 0.00001$); $I^2 = 98\%$
Test for overall effect: Z = 0.07 (P = 0.95)

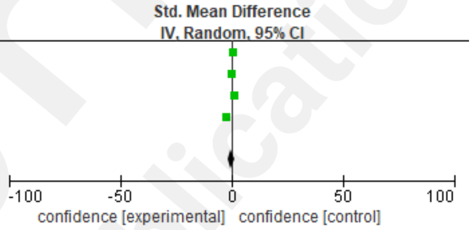



**Figure3c. Meta-analysis of effects of immersive technology education on students' self-efficacy**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn et al 2021 | 0.25 | 0.46 | 44 | 0.01 | 0.64 | 40 | 28.8% | 0.43 [-0.00, 0.86] |
| Lee et al 2022 | 4.03 | 1.722 | 30 | 2.43 | 1.43 | 30 | 25.1% | 1.00 [0.46, 1.54] |
| Yu et al 2021 | 3.21 | 1.462 | 25 | 2.25 | 1.42 | 25 | 24.0% | 0.66 [0.09, 1.23] |
| Yu et al 2022 | 0.6 | 0.564 | 25 | -0.4 | 0.74 | 25 | 22.0% | 1.50 [0.86, 2.13] |
| **Total (95% CI)** | | | **124** | | | **120** | **100.0%** | **0.86 [0.42, 1.31]** |

Heterogeneity: $Tau^2 = 0.13$; $Chi^2 = 8.21$, df = 3 (P = 0.04); $I^2 = 63\%$
Test for overall effect: Z = 3.79 (P = 0.0001)

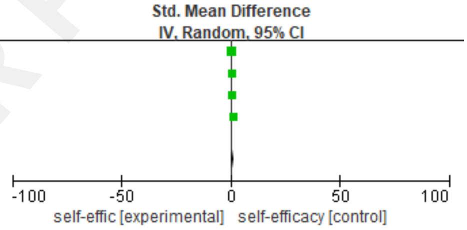
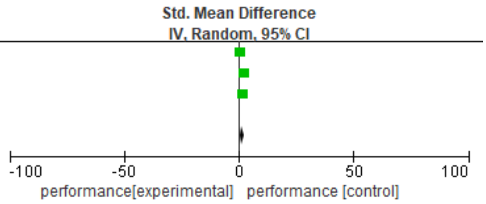



**Figure3d. Meta-analysis of effects of immersive technology education on students' performance**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn et al 2021 | 0.46 | 0.74 | 44 | 0.05 | 0.81 | 40 | 34.3% | 0.52 [0.09, 0.96] |
| Chen et al 2023 | 25.82 | 1.253 | 46 | 22.89 | 1.41 | 49 | 33.6% | 2.17 [1.66, 2.69] |
| Yu et al 2022 | 1.41 | 0.75 | 25 | 0.2 | 0.78 | 25 | 32.1% | 1.56 [0.92, 2.20] |
| **Total (95% CI)** | | | **115** | | | **114** | **100.0%** | **1.41 [0.36, 2.46]** |

Heterogeneity: $Tau^2 = 0.78$; $Chi^2 = 24.00$, df = 2 ($P < 0.00001$); $I^2 = 92\%$
Test for overall effect: Z = 2.64 (P = 0.008)




## Discussion

### Principal findings

This study aims to systematically review the existing literature and conduct a meta-analysis of education centered on immersive technologies, such as VR, AR, MR, and XR, delivered to nursing college students. Out of the 3,204 identified papers, 23 were included in this systematic review. Upon reviewing the selected papers, it became apparent that research on immersive technology-based nursing education has displayed a positive trend over the years. VR has emerged as a prevailing form of immersive technology, and there is a notable preference for VR and AR in contrast to the integration of MR or XR within the domains of nursing education. Among the 19 studies that utilized VR, 17 (90%) employed scenario-based interventions with narrative elements to assess the efficacy of educational programs. Scenario-based learning, which encompasses diverse patient populations in various settings, has become essential in nursing education. In this context, employing VR, which immerses subjects in computer-generated virtual environments, has proven to be an effective approach for conducting interventions [2,10]. Of the four studies focusing on AR, one employed scenario-based interventions featuring narrative elements. The content concerned pediatric cardiopulmonary resuscitation. Owing to the degree of immersion, AR might be adopted as a tool for watching objects rather than narrative simulations.

Four of the 23 studies indicated the educational effectiveness of observations in simulation settings. Observation is a superior learning method in nursing practice. Observers can understand new knowledge from an objective perspective and reflect on the immersive technology. Some studies have emphasized the advantages of observation in learning if it is planned with appropriate pedagogical theories and resources in simulation-based education [32]. Immersive technology has the potential to develop a method of observing in the realm of nursing education, which is now restricted by resource limitations. The outcome variables of the studies comprised three dimensions aligned with the New World–Kirkpatrick model. The first level encompasses variables such as satisfaction and anxiety. At Level 2, the measured variables included knowledge, performance, motivation, attitude, and self-efficacy. Additionally, the outcome variable associated with Level 3 centered exclusively on clinical reasoning, whereas no variables pertinent to Level 4 were identified. This finding aligns with the ongoing challenge of assessing the long-term effects of nursing education on professional nursing practice outcomes. To facilitate evaluation at Level 4, preparation for assessing the achievement of the initial learning indicators in the educational program is necessary. In other words, it is imperative to undertake longitudinal studies such as cohort studies, which can provide insights into the long-term impact of immersive technology in clinical settings to ascertain the sustained efficacy of education facilitated by immersive technology in clinical settings [33].

This meta-analysis reveals that VR-based instruction has the potential to enhance knowledge attainment, self-efficacy, and performance among college nursing students. However, no statistically significant differences were observed in the confidence enhancement between the traditional and VR methods.

### Limitations and the future research

This study has several limitations. The major limitation of this meta-analysis is the large heterogeneity between studies, which requires careful interpretation of the research findings. Various types of software and equipment were used for the interventions, and the results from each study may vary owing to differences in technical functions. Second, the inclusion of only studies written in English may have generated a bias in the analysis. Third, to ensure the quality of the studies, we included only those published in peer-reviewed journals. Relevant materials, such as conference proceedings, books, online websites, and other sources, can be overlooked. Finally, synthesizing the effectiveness of immersive technology in education is challenging, and the choice of technology application varies based on available sources, infrastructure, and educators' judgment. Therefore, the Gartner Hype Cycle is recommended as a reference for researchers seeking to leverage technology for advancement in education. The Gartner Hype Cycle guides researchers in understanding the trends of emerging technologies and proposes key factors for operating technological performance [34].

### Comparison with prior work

With the growing prevalence of immersive technology in academia, numerous scholars have assessed its effectiveness through systematic reviews and meta-analysis. Among these scholarly endeavors, a significant number of research papers have focused on the application of Virtual Reality(VR) in educational contexts [35-37]. The literature reviews included studies that verified the efficacy of VR in nursing education [10] and investigated the effects of VR education on specific outcome variables [35,37-38]. However, comprehensive literature reviews incorporating immersive technologies beyond VR are scarce. Notably, a single study by Ryan (2022) has systematically addressed the learning outcomes associated with immersive technologies, including VR and AR [2]. Given this context, it is imperative to comprehend the educational effects of immersive technologies including not only VR but also AR, MR, and XR in light of their escalating role in the realm of instructional practices.

The categorization of VR into immersive, semi-immersive, and non-immersive VR stems from Cipresso (2018) [5]. However, most prior studies conducted literature reviews without distinguishing between immersion-based VR categories. Only a few studies have conducted literature reviews that consider the distinction of VR based on immersion levels [13,36]. Given the variability in educational effects based on the degree of immersion [39], it is crucial to classify VR according to the level of immersion in order to ascertain its educational impact. Therefore, this study was specifically confined to VR, which utilizes HMD.

Although research on the effectiveness of immersive technology education is ongoing, it is crucial to define and explore the impact of immersive technologies, including VR and AR, on the education of nursing students. This study investigated holistic educational effects without restrictions on scenarios or outcomes, contributing to a comprehensive understanding of the influence of immersive technology.

By applying a theoretical framework, the results of interventions or research can be validated, and it is more useful to determine distinctions under the same standard. Previous studies on nursing education, several review studies had assessed program effectiveness based on the NWKM [40-44]. Corresponding to the results of our study, the outcomes pertinent to Levels 1 and 2 were most frequently evaluated. Although the NWKM emphasizes the importance of Level 4, few studies have explored Level 4 outcomes [43, 44]. And two studies conducted meta-analysis based on NWKM. Delisle (2019) conducted a meta-analysis comparing the learning effectiveness of observers with active participants in healthcare simulation, finding no statistically significant differences in subgroup analysis of NWKM level 2 outcomes [40]. Piot (2022) implemented a meta-analysis comparing the learning effectiveness of various simulation types and reported that simulation effects on skills and attitudes, categorized as Level 2, were more effective than comparisons, while the impact on knowledge did not reach statistical significance [42]. It is important to note that this research encompassed various simulation methods and did not include a meta-analysis specifically on immersive technologies. To the best of our knowledge, this is the first study to compare the effectiveness of traditional and immersive technology.

## Conclusions

The results of this meta-analysis offer insights into the current application of immersive technology in nursing education among college nursing students. This study recognized that immersive technology has the potential to enhance knowledge attainment, self-efficacy, and performance. Its integration is anticipated to support the transition of nursing college students into clinical nurses, despite confidence enhancement emerging as a non-significant variable in comparison with traditional education. Notably, the outcome variables predominantly aligned with Levels 1 to 3 of the New World Kirkpatrick Model. Therefore, the recommendation for future research emphasizes exploring the enduring effects of immersive technology in the realm of nursing education.

## Acknowledgements

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## Conflicts of Interest

None declared

## Abbreviations

ABCDE: Airway, breathing, circulation, disability, exposure
AI: Artificial Intelligence
APGAR: Appearance, pulse, grimace, activity, and respiration
AR: Augmented Reality
CI: Confidence Interval
CINAHL: Cumulative Index to Nursing and Allied Health Literature
COVID 19: coronavirus disease 2019
CPR: Cardiopulmonary resuscitation
ER: Emergency Room
HirNIC: High-risk neonatal infection control
HMD: Head-Mounted Device
HVRS: Home-visits virtual reality simulation
ICU: Intensive Care Units
ICT: Information and Communications Technology
IM: Intramuscular
IV: Intravenous
LCD: Liquid Crystal Display
MeSH: Medical Subject Headings
Min: Minutes
MR: Mixed Reality
MSIT: Master of Science in Information Technology
NG: Nasogastric
NICU: Neonatal Intensive Care Units
NRF: National Research Foundation
NWKM: New World Kirkpatrick Model
OR: Operating Rooms
PC: Personal Computer
PPE: Personal protective equipment

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROSPERO: International Prospective Register of Systematic Reviews
RCT: Randomized controlled trials
RoB: Risk-of-Bias tool
RoBANS: Risk of Bias Assessment tool for Non-Randomized Studies
SC: Subcutaneous
SMD: Standardized Mean Difference
SVVR: Spherical Video-based Virtual Reality
USA: United States of America
VR: Virtual Reality
VRICS: Virtual Reality Infection Control Simulation
VRP: Virtual Reality Nursing Education Program
XR: Extended Reality
3D: Three-dimensional

## References

1. Fealy S, Jones D, Hutton A, et al. The integration of immersive virtual reality in tertiary nursing and midwifery education: A scoping review. *Nurse Educ Today*. 2019;79:14-19. doi:10.1016/j.nedt.2019.05.002
2.Ryan GV, Callaghan S, Rafferty A, Higgins MF, Mangina E, McAuliffe F. Learning Outcomes of Immersive Technologies in Health Care Student Education: Systematic Review of the Literature. *J Med Internet Res*. 2022;24(2):e30082. Published 2022 Feb 1. doi:10.2196/30082
3.Sutherland IE. Sketch pad a man-machine graphical communication system. *Proceedings of the SHARE design automation workshop on - DAC '64*. Published online 1964. doi:https://doi.org/10.1145/800265.810742
4.Tang YM, Chau KY, Kwok APK, Zhu T, Ma X. A systematic review of immersive technology applications for medical practice and education - Trends, application areas, recipients, teaching contents, evaluation methods, and performance. *Educational Research Review*. 2022;35:100429. doi:https://doi.org/10.1016/j.edurev.2021.100429
5. Cipresso P, Giglioli IAC, Raya MA, Riva G. The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature. *Front Psychol*. 2018;9:2086. Published 2018 Nov 6. doi:10.3389/fpsyg.2018.02086
6. INACSL Committee, Penni I. Watts, Donna S. McDermott, Guillaume Alinier, Matthew Charnetski, Jocelyn Ludlow, Elizabeth Horsley, Colleen Meakim, Pooja A. Nawathe. Healthcare Simulation Standards of Best Practice™ Simulation Design. *Clin Simul Nurs*. 2021;58,:14-21. https://doi.org/10.1016/j.ecns.2021.08.009.
7. Bowers B, McCarthy D. Developing analytic thinking skills in early undergraduate education. *J Nurs Educ*. 1993;32(3):107-114. doi:10.3928/0148-4834-19930301-05
8. Shin S, Park JH, Kim JH. Effectiveness of patient simulation in nursing education: meta-analysis. *Nurse Educ Today*. 2015;35(1):176-182. doi:10.1016/j.nedt.2014.09.009
9. Uysal N. Improvement of nursing students' learning outcomes through scenario-based skills training. *Rev Lat Am Enfermagem*. 2016;24:e2790. doi:10.1590/1518-8345.1310.2790
10. Chen FQ, Leng YF, Ge JF, et al. Effectiveness of Virtual Reality in Nursing Education: Meta-Analysis. *J Med Internet Res*. 2020;22(9):e18290. Published 2020 Sep 15. doi:10.2196/18290

11. Jeffries PR, Bambini D, Hensel D, Moorman M, Washburn J. Constructing maternal-child learning experiences using clinical simulations. *J Obstet Gynecol Neonatal Nurs*. 2009;38(5):613-623. doi:10.1111/j.1552-6909.2009.01060.x
12. Saab MM, Hegarty J, Murphy D, Landers M. Incorporating virtual reality in nurse education: A qualitative study of nursing students' perspectives. *Nurse Educ Today*. 2021;105:105045. doi:10.1016/j.nedt.2021.105045
13. Choi J, Thompson CE, Choi J, Waddill CB, Choi S. Effectiveness of Immersive Virtual Reality in Nursing Education: Systematic Review. *Nurse Educ*. 2022;47(3):E57-E61. doi:10.1097/NNE.0000000000001117
14.Cobbett S, Snelgrove-Clarke E. Virtual versus face-to-face clinical simulation in relation to student knowledge, anxiety, and self-confidence in maternal-newborn nursing: A randomized controlled trial. *Nurse Educ Today*. 2016;45:179-184. doi:10.1016/j.nedt.2016.08.004
15. Foronda C, Gattamorta K, Snowden K, Bauman EB. Use of virtual clinical simulation to improve communication skills of baccalaureate nursing students: a pilot study. *Nurse Educ Today*. 2014;34(6):e53-e57. doi:10.1016/j.nedt.2013.10.007
17. Rim D, Shin H. Effective instructional design template for virtual simulations in nursing education. *Nurse Educ Today*. 2021;96:104624. doi:10.1016/j.nedt.2020.104624
18. Jenson CE, Forsyth DM. Virtual reality simulation: using three-dimensional technology to teach nursing students. *Comput Inform Nurs*. 2012;30(6):312-320. doi:10.1097/NXN.0b013e31824af6ae
19. Jeffries PR, Rodgers B, Adamson K. NLN Jeffries Simulation Theory: Brief Narrative Description. *Nursing Education Perspectives.* 2015; 36 (5): 292-293.
20. Kirkpatrick JD, Kirkpatrick WK. *Kirkpatrick's Four Levels of Training Evaluation*. Association for Talent Development; 2016.
21. Liao S-C, Hsu S-Y. Evaluating A Continuing Medical Education Program: New World Kirkpatrick Model Approach. International Journal of Management, Economics and Social Sciences. 12/20 2019;8doi:10.32327/IJMESS/8.4.2019.17
22. Huang X, Wang R, Chen J, et al. Kirkpatrick's evaluation of the effect of a nursing innovation team training for clinical nurses. *J Nurs Manag*. 2022;30(7):2165-2175. doi:10.1111/jonm.13504
23, Johnston S, Fox A. Kirkpatrick's Evaluation of Teaching and Learning Approaches of Workplace Violence Education Programs for Undergraduate Nursing Students: A Systematic Review. *J Nurs Educ*. 2020;59(8):439-447. doi:10.3928/01484834-20200723-04
24. Lee H, Song Y. Kirkpatrick Model Evaluation of Accelerated Second-Degree Nursing Programs: A Scoping Review. *J Nurs Educ*. 2021;60(5):265-271. doi:10.3928/01484834-20210420-05
25, Bryant R, Miller CL, Henderson D. Virtual Clinical Simulations in an Online Advanced Health Appraisal Course. *Clinical Simulation in Nursing*. 2015;11(10):437-444. doi:https://doi.org/10.1016/j.ecns.2015.08.002
26. Farra SL, Smith S, Gillespie GL, et al. Decontamination training: with and without virtual reality simulation. *Adv Emerg Nurs J*. 2015;37(2):125-133. doi:10.1097/TME.0000000000000059
27. Liu JYW, Yin YH, Kor PPK, et al. The Effects of Immersive Virtual Reality Applications on Enhancing the Learning Outcomes of Undergraduate Health Care Students: Systematic Review With Meta-synthesis. *J Med Internet Res*. 2023;25:e39989. Published 2023 Mar 6. doi:10.2196/39989

28. Jung AR, Park EA. The Effectiveness of Learning to Use HMD-Based VR Technologies on Nursing Students: Chemoport Insertion Surgery. *Int J Environ Res Public Health*. 2022;19(8):4823. Published 2022 Apr 15. doi:10.3390/ijerph19084823
29. Lee H, Han JW. Development and evaluation of a virtual reality mechanical ventilation education program for nursing students. *BMC Med Educ*. 2022;22(1):775. Published 2022 Nov 10. doi:10.1186/s12909-022-03834-5
30. Follmann D, Elliott P, Suh I, Cutler J. Variance imputation for overviews of clinical trials with continuous response. *J Clin Epidemiol*. 1992 Jul;45(7):769-73. doi: 10.1016/0895-4356(92)90054-q. PMID: 1619456.
31. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557-560. doi:10.1136/bmj.327.7414.557
32. Delisle M, Ward MAR, Pradarelli JC, Panda N, Howard JD, Hannenberg AA. Comparing the Learning Effectiveness of Healthcare Simulation in the Observer Versus Active Role: Systematic Review and Meta-Analysis. Simul Healthc. 2019;14(5):318-332. doi:10.1097/SIH.0000000000000377
33. Caruana EJ, Roman M, Hernández-Sánchez J, Solli P. Longitudinal studies. *J Thorac Dis*. 2015;7(11):E537-E540. doi:10.3978/j.issn.2072-1439.2015.10.63
34. Gartner Hype Cycle. updated 2024. Gartner Inc. https://www.gartner.com/en/research/methodologies/gartner-hype-cycle
35. Rourke S. How does virtual reality simulation compare to simulated practice in the acquisition of clinical psychomotor skills for pre-registration student nurses? A systematic review. Int J Nurs Stud. 2020;102:103466. doi:10.1016/j.ijnurstu.2019.103466
36. Plotzky C, Lindwedel U, Sorber M, et al. Virtual reality simulations in nurse education: A systematic mapping review. Nurse Educ Today. 2021;101:104868. doi:10.1016/j.nedt.2021.104868
37. Woon APN, Mok WQ, Chieng YJS, et al. Effectiveness of virtual reality training in improving knowledge among nursing students: A systematic review, meta-analysis and meta-regression. Nurse Educ Today. 2021;98:104655. doi:10.1016/j.nedt.2020.104655
38. Jallad ST, Işık B. The effectiveness of virtual reality simulation as learning strategy in the acquisition of medical skills in nursing education: a systematic review. Ir J Med Sci. 2022;191(3):1407-1426. doi:10.1007/s11845-021-02695-z
39. Lønne TF, Karlsen HR, Langvik E, Saksvik-Lehouillier I. The effect of immersion on sense of presence and affect when experiencing an educational scenario in virtual reality: A randomized controlled study. Heliyon. 2023;9(6):e17196. Published 2023 Jun 12. doi:10.1016/j.heliyon.2023.e17196
40. Delisle M, Ward MAR, Pradarelli JC, Panda N, Howard JD, Hannenberg AA. Comparing the Learning Effectiveness of Healthcare Simulation in the Observer Versus Active Role: Systematic Review and Meta-Analysis. Simul Healthc. 2019;14(5):318-332. doi:10.1097/SIH.0000000000000377
41. Griffiths M, Creedy D, Carter A, Donnellan-Fernandez R. Systematic review of interventions to enhance preceptors' role in undergraduate health student clinical learning.*Nurse Educ Pract*. 2022;62:103349. doi:10.1016/j.nepr.2022.103349
42. Piot MA, Dechartres A, Attoe C, et al. Effectiveness of simulation in psychiatry for nursing students, nurses and nurse practitioners: A systematic review and meta-analysis. J Adv Nurs. 2022;78(2):332-347. doi:10.1111/jan.14986
43. Lee E, De Gagne JC, Randall PS, Kim H, Tuttle B. Effectiveness of speak-up training programs for clinical nurses: A scoping review.*Int J Nurs Stud*. 2022;136:104375. doi:10.1016/j.ijnurstu.2022.104375
44. Vinette B, Lapierre A, Lavoie A, Leclerc-Loiselle J, Charette M, Deschênes MF. Educational

strategies used in master's and doctoral nursing education: A scoping review. *J Prof Nurs*. 2023;48:84-92. doi:10.1016/j.profnurs.2023.06.006

# Supplementary Files

# Multimedia Appendixes

List of included papers.
URL: http://asset.jmir.pub/assets/ce754eea574c574c934a95cd028e786c.docx

Definition of immersive technology.
URL: http://asset.jmir.pub/assets/f95489a5801f612a8e0980d073edef80.docx

Search term.
URL: http://asset.jmir.pub/assets/3dbabe6c9bd220e12f94b02ddbc72d6a.docx