BMC Nursing

RESEARCH

Open Access

Virtual reality simulation for high-risk neonatal emergency nursing training: a mixed-methods study on nurse competency and outcomes

Abeer Nuwayfi Alruwaili[1*], Afrah Madyan Alshammari[2], Ali Alhaiti[3], Nadia Bassuoni Elsharkawy[2], Sayed Ibrahim Ali[4] and Osama Mohamed Elsayed Ramadan[5*]

Abstract

Background Nurses in neonatal intensive care units face critical challenges in managing emergencies where timely, accurate interventions are essential for survival. Traditional nursing education often lacks the hands-on, immersive training required to build complex emergency skills, contributing to persistent neonatal mortality globally. Virtual reality (VR) simulation, grounded in Kolb's Experiential Learning Theory, offers a promising solution by replicating realistic and repeatable clinical scenarios. While VR has shown potential in nursing education, its specific impact on high-risk neonatal emergencies remains underexplored.

Aim To evaluate the effectiveness of a VR simulation program in enhancing nurse competency and improving neonatal outcomes during emergency care, grounded in Kolb's Experiential Learning Theory.

Methods A concurrent triangulation mixed-methods design was implemented over two weeks across four pediatric hospitals. Through stratified random sampling, 128 NICU nurses were allocated to VR simulation ($n = 64$) or traditional training ($n = 64$) groups. Quantitative data were collected using validated instruments (OSCE: CVI = 0.92, MCQ: α = 0.86) measuring clinical skills, knowledge retention, and decision-making accuracy. Qualitative data were gathered through semi-structured interviews ($n = 24$) exploring experiential aspects.

Results The VR group showed significant improvements in clinical skills (OSCE: +16.1 points, $p < 0.001$, d = 1.58), decision-making accuracy (+16.7%, $p < 0.001$), and reduced stabilization times (-6.2 min, $p < 0.001$). Patient safety events decreased by 52% ($p < 0.001$). Thematic analysis revealed enhanced professional competence (83%), reduced clinical anxiety (75%), and positive learning experiences (88%), despite minor technical challenges.

Conclusion VR simulation demonstrates superior effectiveness for neonatal emergency training, significantly improving both nurse competency and patient outcomes. While geographic specificity and brief follow-up duration limit generalizability, findings support VR's potential for enhancing emergency preparedness. Future research should address longitudinal outcomes and implementation across diverse healthcare settings.

*Correspondence:
Abeer Nuwayfi Alruwaili
analrwili@ju.edu.sa
Osama Mohamed Elsayed Ramadan
osama_ramadan_85@cu.edu.eg

Full list of author information is available at the end of the article

Clinical trial number Not applicable.

Keywords Virtual reality simulation, Neonatal emergency care, Nursing education, Mixed-methods research, Clinical competency, Patient outcomes

Introduction

Neonatal emergencies remain a critical global health challenge, significantly contributing to infant morbidity and mortality rates worldwide [1, 2]. Approximately 2.4 million neonates die each year, many from preventable or manageable conditions requiring timely and effective interventions [3]. High-risk neonatal situations demand prompt and skilled responses from healthcare professionals, particularly nurses, who are often the first responders in critical care settings [4]. However, traditional training approaches for emergency response in neonatal nursing, such as classroom-based instruction, observational learning, and the use of static mannequins, may not adequately prepare nurses for the complexities and high-pressure environments of real-life clinical scenarios [5, 6].

Virtual reality (VR) simulation has emerged as an innovative tool in healthcare education, offering immersive and interactive environments that closely mimic real-world clinical situations [7, 8]. VR simulation enhances clinical skills, decision-making abilities, and confidence levels by enabling learners to engage in realistic practice without the risks associated with actual patient care [9]. In general nursing education, VR has demonstrated significant success in training for various clinical scenarios, including emergency response protocols, critical care interventions, and complex procedural skills [10]. Studies have shown improved learning outcomes, enhanced retention rates, and increased confidence levels among nurses using VR-based training programs [11–13]. However, despite these promising results in general nursing applications, the implementation of VR technology in neonatal nursing training, particularly for emergency response, remains limited and underdeveloped [14]. This gap is particularly concerning given the unique challenges and high-stakes nature of neonatal care, where specialized training modalities could significantly impact patient outcomes [15, 16].

A critical gap exists in the literature regarding the effectiveness of VR-based emergency response training tailored specifically for high-risk neonatal care [5, 17]. Existing studies often lack integration of VR simulations that accurately represent neonatal physiology and pathology, incorporate realistic emergency scenarios, and measure outcomes related to both nurse competency and neonatal patient outcomes [18–21]. Methodological gaps include a scarcity of randomized controlled trials assessing VR training efficacy in neonatal settings and insufficient quantitative evidence measuring the impact on clinical performance metrics and patient outcomes [22]. Moreover, the perceptions and acceptance of VR technology among practicing neonatal nurses have not been extensively studied, which is essential for successful integration into nursing education and practice [23–26].

This study examines several key variables to evaluate the effectiveness of VR simulation in neonatal emergency response training. The primary independent variable is the specialized VR simulation training program, which incorporates advanced physiological modelling and realistic emergency scenarios. The dependent variables include both nurse competency measures (clinical skills, knowledge assessment scores, decision-making speed and accuracy, and confidence levels) and neonatal outcomes (stabilization times, successful intervention rates, and patient safety indicators). Control variables include traditional training methods used in the comparison group: standard classroom instruction and static mannequin simulation. Potential confounding variables, such as prior nursing experience and technological proficiency, were addressed through proportional allocation and statistical adjustments.

This study addressed these gaps by implementing a novel VR simulation program designed specifically for high-risk neonatal emergency response training. The VR system incorporates advanced physiological modelling of neonates' realistic emergency scenarios, such as respiratory distress and cardiac arrest, and provides real-time feedback to learners. This innovative approach enhances the realism of training and allows for the assessment of critical thinking and adaptability in dynamic situations. By employing a mixed-methods design that includes quantitative measures of nurse competency and neonatal outcomes, as well as qualitative assessments of user experiences [27], this research offers a comprehensive evaluation of VR simulation in this context.

The practical implications of this study are significant. Improving nurse competency through specialized VR training has the potential to enhance the quality of patient care and reduce neonatal morbidity and mortality rates [28]. VR technology's scalability and accessibility make it a viable solution for widespread training, addressing resource limitations associated with traditional simulation methods [29, 30]. Furthermore, this research contributes novel evidence on the implementation of VR technology in neonatal emergency response training, informing educational practices and policymaking on a global scale.

The theoretical framework underpinning this study was Kolb's Experiential Learning Theory (Fig. 1), which posits that learning occurs through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation [31, 32]. As shown in Fig. 1, VR simulation serves as the primary training input (independent variable) that integrates with this learning cycle. The framework demonstrated how VR simulation aligned with each stage of Kolb's theory: providing concrete experience through VR scenarios, enabling reflective observation through performance review, facilitating abstract conceptualization through knowledge integration, and supporting active experimentation through skill application. This comprehensive framework also incorporates control variables (prior experience, tech proficiency, and traditional training) and measures both nurse outcomes and neonatal outcomes as dependent variables. The interactive nature of VR allowed nurses to engage fully in this learning cycle, enhancing retention and skill acquisition.

Operational definitions

- ***Nurse competency***: A combination of clinical skills, knowledge retention, decision-making speed and accuracy, and confidence levels enabling nurses to effectively manage neonatal emergencies. Competency was measured using standardized clinical skills assessments, knowledge tests, timed decision-making scenarios, and validated confidence rating scales.
- ***Neonatal outcomes***: Clinical indicators reflecting the health status of neonates during and after emergency interventions. These include stabilization times, successful intervention rates, and patient safety metrics. These metrics are chosen as they provide direct, measurable indicators of neonatal well-being during emergencies.
- ***Traditional training methods***: Standard classroom instruction and static mannequin simulations currently used in neonatal emergency response training. These lack the immersive and interactive features of VR technology and serve as the control group in this study.
- ***Positive experiences and perceptions***: Nurses' subjective evaluations of the VR training program, including satisfaction, perceived effectiveness, ease of use, and willingness to integrate the technology into practice. These were assessed through structured surveys and semi-structured interviews. The reflections will also be analyzed through the lens of Kolb's Reflective Observation stage to capture experiential insights.
- ***Control Variables***: Factors such as prior experience in neonatal emergencies, technology proficiency, and exposure to traditional training methods. These were statistically controlled to isolate the effect of VR simulation on outcomes.

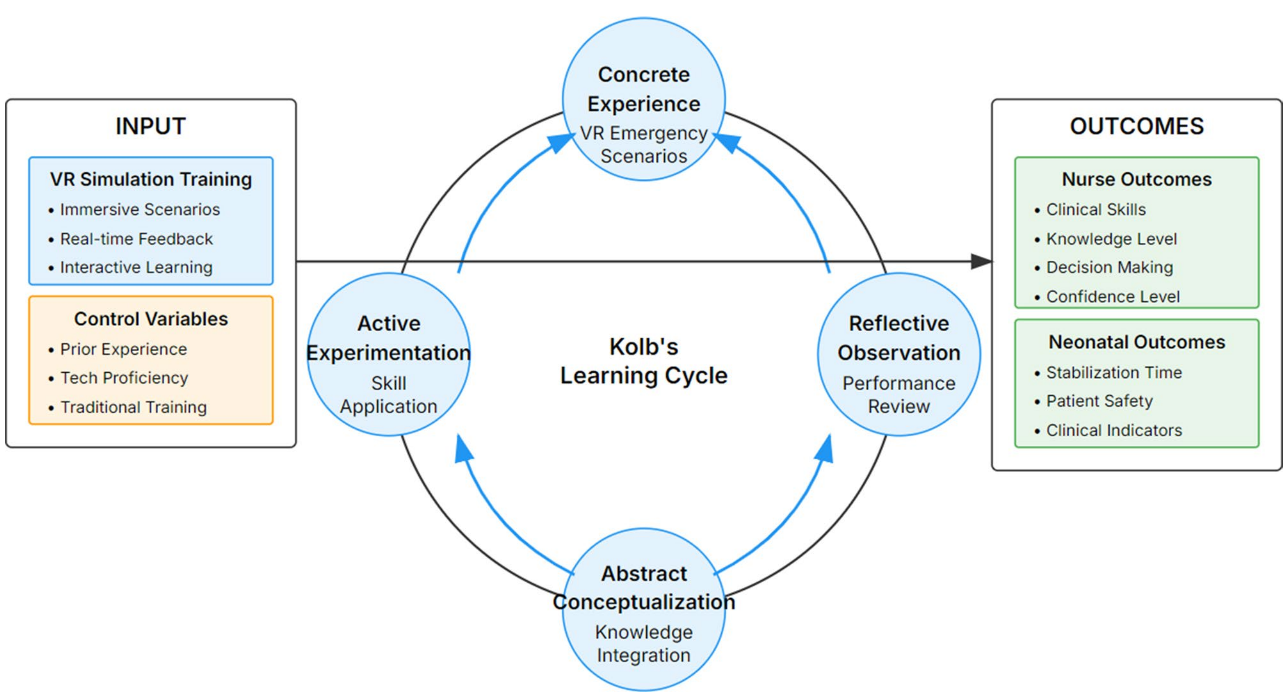

Fig. 1 Theoretical framework for VR simulation-based training in neonatal emergency response: integration of Kolb's experiential learning theory

This study aimed to evaluate the effectiveness of a specialized virtual reality (VR) simulation-based emergency response training program on nurse competency and neonatal outcomes in high-risk neonatal nursing settings within the framework of Kolb's Experiential Learning Theory.

Research question

How do nurses experience, perceive, and accept specialized VR simulation training as a tool for emergency response in neonatal nursing?

Objectives

1. *To determine the impact of VR simulation training on nurses' clinical skills, knowledge retention, decision-making speed and accuracy, and confidence levels in managing neonatal emergencies, compared to traditional training methods using standardized assessment tools.*
2. *To measure the effect of enhanced nurse competency resulting from VR training on neonatal clinical outcomes during emergency situations by evaluating clinical indicators such as stabilization times, successful intervention rates, and patient safety metrics.*
3. *To explore nurses' experiences, perceptions, and acceptance of the specialized VR simulation as a tool for emergency response training in neonatal care. This qualitative exploration will leverage structured surveys and semi-structured interviews, analyzed within the framework of Kolb's Experiential Learning Theory, particularly the Reflective Observation and Abstract Conceptualization stages.*

The hypotheses were as follows:

- ***H1***: *Nurses who receive specialized VR simulation-based emergency response training will demonstrate significantly higher competency levels measured by clinical skills assessments, knowledge tests, decision-making speed and accuracy, and confidence rating scales than those who receive traditional training methods.*
- ***H2***: *Enhanced nurse competency through VR training will causally lead to improved neonatal outcomes, evidenced by shorter stabilization times, higher successful intervention rates, and better patient safety metrics during emergencies compared to traditional training methods.*
- ***H3***: *Nurses will report positive experiences and perceive the specialized VR simulation as an effective, immersive, and valuable modality for emergency response training in neonatal nursing. This will be indicated by high satisfaction scores and affirmative feedback in surveys and interviews.*

Materials and methods

Study design

This study utilized a concurrent triangulation mixed-methods design, with equal emphasis on quantitative and qualitative components. The quantitative strand assessed the effectiveness of VR simulation training on nurse competency metrics and neonatal outcomes using validated pre- and post-intervention measures. The qualitative strand explored participants' lived experiences and perceptions of the VR training program through semi-structured interviews. Data integration occurred during both collection and analysis phases, following Creswell and Plano Clark's convergent parallel design. This approach ensured complementarity, providing a comprehensive evaluation of the intervention's impact.

Settings

The study was conducted across four major pediatric hospitals in the Eastern Province of Saudi Arabia: King Fahad Hospital in Al-Ahsa, Maternity and Children Hospital in Dammam, King Khalid General Hospital in Hafr Al-Batin, and Al-Mousa Specialist Hospital. These hospitals were selected for their role as primary referral centres for high-risk neonatal care, collectively serving a population of approximately 5.3 million residents. Each hospital is equipped with a Level III Neonatal Intensive Care Unit (NICU), offering standardized emergency response protocols and advanced neonatal care capabilities.

Participants

The study included two participant groups, reflecting its mixed-methods design. A total of 128 NICU nurses were recruited using stratified random sampling, ensuring proportional representation across the four hospitals. Inclusion criteria required participants to be registered nurses with at least one year of NICU experience, full-time employment at one of the participating hospitals, and no prior exposure to VR-based neonatal training. Nurses in temporary positions, those concurrently enrolled in other training programs, or those with conditions contraindicating VR use (e.g., vestibular disorders or severe motion sickness) were excluded. While participants were not randomized, proportional allocation aimed to reduce the influence of confounding variables such as clinical experience and technological proficiency. Any residual confounding effects were addressed through statistical adjustments in the analysis phase.

Quantitative strand

The quantitative sample size was determined using G*Power (version 3.1.9.7), assuming a medium effect size (d = 0.5), α = 0.05, and power of 0.80. The calculated sample size was 128, with 64 participants in each group. Participants were allocated to the VR simulation and traditional training groups based on a proportional representation of hospitals and clinical experience to achieve comparable baseline characteristics.

Qualitative strand

For the qualitative component, 24 participants from the VR simulation group were purposively sampled to ensure diversity in age, clinical experience, and technological proficiency. Data saturation, defined as the point at which no new themes emerged during analysis, was achieved after 22 interviews. Two additional interviews were conducted to confirm saturation, ensuring comprehensive insights into participant experiences. Written informed consent was obtained from all participants before enrolment, and ethical approval for the study was granted by the relevant institutional review boards of the participating hospitals.

Data collection tools

To ensure rigor and reliability in our study, we employed a combination of previously validated instruments and tools developed specifically for this research. Each tool was carefully selected or created to align with the study objectives and Kolb's Experiential Learning Theory [33]. For those instruments developed for this study, an English language version is provided as Supplementary File 1.pdf.

Pilot study and instrument refinement Prior to formal data collection, we conducted a pilot study with a small subset of NICU nurses ($n = 15$) to evaluate the clarity, feasibility, and time requirements of our newly developed instruments (i.e., MCQ, VACER, CPCS, and semi-structured interview guide). Feedback from this pilot phase highlighted minor issues such as ambiguous wording in certain MCQ items, overly broad interview questions, and occasional technical glitches with the VACER tool. These insights guided small revisions to item phrasing, interview flow, and VR software stability before launching the main study.

Objective Structured Clinical Examination (OSCE) Checklist The OSCE checklist was adapted from the National Neonatal Resuscitation Protocol Guidelines to assess critical clinical skills including airway management, resuscitation techniques, and medication administration in high-risk neonatal emergencies [34]. A modified Delphi process with eight neonatal nursing experts resulted in a high Content Validity Index (CVI = 0.92). Its reliability was confirmed by inter-rater reliability (ICC = 0.87, 95% CI: 0.83–0.91) and test-retest reliability ($r = 0.85$).

Multiple-Choice Questionnaire (MCQ) Knowledge of neonatal emergency protocols was measured using a 50-item MCQ developed exclusively for this study. Items were generated through systematic item analysis and expert review, and pilot testing with 15 NICU nurses established strong internal consistency (Cronbach's α = 0.86) and construct validity (KMO = 0.82). Criterion validity was further supported by a positive correlation ($r = 0.78$) with an established, validated knowledge assessment tool.

Virtual Reality-Based Assessment of Clinical Emergency Response (VACER) The VACER tool, developed for this study and integrated into the VR simulation environment, objectively measured decision-making competency by recording response times and evaluating the appropriateness of clinical interventions. Validation studies demonstrated strong concurrent validity ($r = 0.82$, $p < 0.001$) when compared with traditional assessment methods.

Confidence in performing clinical skills (CPCS) scale A 20-item Likert scale, the CPCS was developed to assess self-reported confidence in performing critical clinical skills. The scale demonstrated excellent internal consistency (Cronbach's α = 0.92) and robust construct validity, as evidenced by a Comparative Fit Index (CFI = 0.95) and a Root Mean Square Error of Approximation (RMSEA = 0.06).

Neonatal Outcome Metrics Neonatal outcomes were objectively evaluated through stabilization times, successful intervention rates, and patient safety events automatically recorded by the VR system. The measurement system showed strong concordance (correlation coefficient = 0.89) with direct observational measures. During the pilot phase, we confirmed that these outcome metrics were captured accurately and consistently by the system.

Semi-Structured Interviews To capture qualitative insights into participants' experiences with the VR training program, we developed a semi-structured interview guide grounded in Kolb's Experiential Learning Theory [33]. The guide's content validity was first ensured through expert review by nine professionals with expertise in neonatal nursing, simulation-based learning, and qualitative research. Each question was evaluated for relevance, clarity, and alignment with the study objectives, yielding a Content Validity Ratio (CVR) of 0.86 surpassing the recommended threshold for acceptable content validity. A pilot test with three volunteers from the participant pool further addressed face validity by identifying any ambiguous wording, overly broad questions, or confusing transitions. Based on this feedback, minor revisions were made to question phrasing and sequencing, resulting in a smoother flow and clearer prompts. The final guide consists of open-ended questions designed to elicit rich, detailed responses about participants' personal experiences, reflections, and suggestions for future training.

Regarding reliability, each interview was conducted using the same structured protocol (introduction, main questions, probes, and concluding remarks). Interviews typically lasted 45–60 min and were audio-recorded with participants' consent, then transcribed verbatim. To enhance coding reliability during thematic analysis, two independent researchers coded a subset of transcripts, achieving a high level of agreement (Cohen's $\kappa = 0.85$). Any discrepancies were discussed and resolved collaboratively, thereby promoting consistency and dependability in interpreting the qualitative data. This approach to instrument development and testing ensured that the semi-structured interviews not only aligned with the theoretical framework but also met rigorous standards of validity and reliability, thereby providing a robust platform for exploring the nuanced experiences and perceptions of nurses undergoing VR-based neonatal emergency training.

Simulation structure

The VR simulation program was conducted in three sessions over two weeks, each lasting 2–2.5 h. The simulation design adhered to evidence-based pedagogical principles and was structured as follows:

1. *Pre-Briefing Phase (20–30 min)*: Participants were oriented to the VR platform and session objectives. Key clinical protocols were reviewed to ensure a consistent knowledge baseline and psychological safety was established.
2. *Core Simulation Phase (45–60 min)*: Participants engaged in progressively complex scenarios, including respiratory distress management, cardiac arrest response, and sepsis intervention. The VR platform provided real-time feedback on procedural *accuracy, response times, and adherence to neonatal guidelines.*
3. *Debriefing Phase (45–60 min)*: Guided by the PEARLS framework, participants reflected on their performance, linked actions to theoretical principles, and planned applications for clinical practice.

Study procedures

The study followed a structured sequence to implement the intervention and collect data.

1. *Participant Recruitment and Allocation*: NICU nurses were recruited as described in Sect. "Participants". Allocation to training groups ensured baseline comparability between the VR simulation and traditional training groups.
2. *Pre-Intervention Assessments*: Baseline data were collected using the validated tools detailed in Sect. "Data Collection Tools", measuring knowledge, clinical skills, decision-making competency, and confidence levels.
3. *Training Implementation*: The VR group completed the structured simulation sessions outlined in Sect. "Simulation Structure". The traditional training group received hospital-standard protocols, which included classroom lectures, static mannequin simulations, and supervised clinical practice. The curriculum and delivery were standardized across sites through collaborative planning among the nursing education departments.
4. *Data Collection*: Quantitative data included pre- and post-training assessment scores and performance metrics automatically recorded by the VR system. For the qualitative component, semi-structured interviews were conducted with selected VR group participants.
5. *Post-Intervention Assessments*: Final assessments mirrored the baseline evaluations, measuring changes in competency and confidence. Participant feedback was collected to evaluate the perceived effectiveness of the training program.

Quality control measures

Training of research assistants

Research assistants underwent a two-day training program covering study protocols, data collection tools, and ethical considerations. The training included practical sessions on administering the OSCE checklist, MCQ, and CPCS scale to ensure consistency in assessment procedures.

Standardization across sites

To ensure consistency across the four hospitals, a standardized protocol was developed for all assessments, simulations, and training sessions. Facilitators at each site participated in an orientation workshop to align their instructional approaches with the standardized curriculum.

Data collection quality control

Assessments were conducted under standardized conditions to maintain data integrity. Senior research team members observed all pre- and post-intervention assessments to ensure protocol adherence. An independent reviewer double-checked quantitative data entry to prevent transcription errors. Interview audio recordings were professionally transcribed and verified against the original recordings.

Statistical analysis

The statistical analysis employed a comprehensive mixed-methods approach, integrating both quantitative and qualitative data to ensure a robust evaluation of the study outcomes. Quantitative data were analyzed using SPSS version 27.0. Descriptive statistics were calculated for demographic and baseline variables, with continuous data presented as means and standard deviations and categorical data as frequencies and percentages. Normality of continuous variables was assessed using the Shapiro-Wilk test, with $p > 0.05$ indicating normal distribution. Between-group comparisons of baseline characteristics and pre-intervention measures were conducted using independent t-tests for continuous variables and chi-square tests for categorical variables. Effect sizes were calculated using Cohen's d for continuous variables (small: < 0.2, medium: 0.5, large: > 0.8) and phi coefficient (φ) for categorical variables. Pre-post intervention outcomes were analyzed using mixed-design ANOVA with Bonferroni correction for multiple comparisons. Partial eta squared (η^2) was calculated as the effect size measure (small: 0.01, medium: 0.06, large: > 0.14) to quantify the magnitude of differences. Longitudinal changes across the three training sessions were assessed using repeated measures ANOVA, with post-hoc pairwise comparisons adjusted using the Bonferroni method. Potential confounding variables, including technological proficiency and prior experience, were statistically controlled using multiple regression analysis. Model assumptions were verified, including residual normality (Shapiro-Wilk test), homoscedasticity (Breusch-Pagan test), and multicollinearity assessment (Variance Inflation Factor < 2.5).

For the qualitative component, interview transcripts were analyzed using Braun and Clarke's six-phase thematic analysis approach. Two independent researchers coded the data, achieving high inter-rater reliability (Cohen's kappa, $\kappa = 0.87$). Thematic coding followed a systematic process of familiarization, initial coding, theme development, and refinement. Data saturation was confirmed after 22 interviews, with two additional interviews conducted for validation. Integration of quantitative and qualitative findings was conducted following Creswell and Plano Clark's convergent parallel design, employing joint displays and meta-inferences to synthesize insights from both strands. Statistical significance was set at $p < 0.05$, and all confidence intervals were calculated at the 95% level. Power analysis ensured an adequate sample size to detect medium effect sizes ($d = 0.5$) with 80% power at $\alpha = 0.05$. While the proportional allocation of participants was used to achieve baseline comparability across groups, residual differences in technological proficiency were identified during the analysis phase and accounted for in the regression models.

Ethical considerations

Ethical approval

for this study was obtained from the King Faisal University Ethics Committee (Approval Number: KFU-2024-ETHICS2925). The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their enrollment, ensuring confidentiality and voluntary participation throughout the study.

Results

This mixed-methods study examined the effectiveness of virtual reality (VR) simulation versus traditional training approaches among 128 neonatal intensive care unit (NICU) nurses across four major pediatric hospitals. Following a concurrent triangulation design, the quantitative strand demonstrated baseline equivalence between VR simulation ($n = 64$) and traditional training ($n = 64$) groups across all demographic and professional characteristics. Initial clinical competency measures were comparable between groups, establishing a robust foundation for comparative analysis. The qualitative strand, comprising 24 semi-structured interviews with VR group participants, provided rich insights into the experiential aspects of the training. Through systematic integration of quantitative metrics and qualitative perspectives, our analysis revealed substantial improvements in clinical skills, knowledge retention, and patient outcomes following VR implementation, with notable enhancements in decision-making capabilities and professional confidence. The results are presented according to the study's primary outcomes, reflecting both the depth of quantitative findings and the richness of participants' lived experiences.

Baseline characteristics and group comparability

Initial analysis confirmed comparable baseline characteristics between VR simulation ($n = 64$) and traditional training ($n = 64$) groups. Demographic and professional attributes demonstrated no significant differences across groups, as detailed in Table 1.

Table 1 provides a comprehensive comparison of the socio-demographic and professional characteristics between the VR and traditional training groups, ensuring baseline equivalence critical for the validity of the study findings. Key variables such as age, gender, education level, years of NICU experience, and previous simulation experience were analyzed, with no statistically significant differences observed across the groups (all $p > 0.05$). The groups were closely matched in terms of age (VR:

Table 1 Comparison of Socio-demographic and professional characteristics between VR and traditional training groups ($N = 128$)

Characteristic	VR group ($n = 64$)	Traditional group ($n = 64$)	Test statistic	*p*-value	Effect size
Age (years)	35.2 ± 4.5 (25–45)	34.8 ± 4.7 (24–46)	t = 0.45	0.65	d = 0.09
Gender			$\chi^2 = 0.08$	0.78	φ = 0.03
Female	53 (82.3)	51 (79.7)			
Male	11 (17.7)	13 (20.3)			
Education Level			$\chi^2 = 0.22$	0.64	φ = 0.04
Bachelor's	58 (90.6)	56 (88.2)			
Master's	6 (9.4)	8 (11.8)			
Years of NICU Experience:	7.4 ± 2.1 (3–12)	7.2 ± 2.3 (3–13)	t = 0.36	0.72	d = 0.09
Previous Simulation Experience:			$\chi^2 = 0.39$	0.53	φ = 0.06
Yes	42 (65.6)	40 (62.5)			
No	22 (34.4)	24 (37.5)			

Note: Data are presented as mean ± standard deviation for continuous variables and frequencies (percentages) for categorical variables. Independent t-tests were conducted for continuous variables (normality confirmed via Shapiro-Wilk test, $p > 0.05$) and chi-square tests for categorical variables. Statistical significance was set at $p < 0.05$. Effect sizes were calculated using Cohen's d and phi coefficient (φ). Groups showed no significant baseline differences ($p > 0.05$), with adequate power (β = 0.80) for detecting medium effects (d = 0.5)

35.2 ± 4.5 years; Traditional: 34.8 ± 4.7 years) and NICU experience (VR: 7.4 ± 2.1 years; Traditional: 7.2 ± 2.3 years), as confirmed by independent t-tests, with negligible effect sizes (d = 0.09). Similarly, gender distribution and educational attainment showed parity, with most participants holding a bachelor's degree and a slightly higher proportion of females in both groups. Previous simulation experience was also comparable (VR: 65.6%; Traditional: 62.5%), as indicated by the chi-square test and a small effect size (ϕ = 0.06).

The baseline assessment of clinical competency measures revealed no significant differences between groups across all measured domains, ensuring a robust foundation for intervention comparison (Table 2).

Table 2 compares clinical competency scores between the VR and traditional training groups across key measures: clinical skills, knowledge retention, decision-making accuracy, and confidence levels. The results indicate no statistically significant differences between the groups for any of the competency metrics (all $p > 0.05$), with small effect sizes (Cohen's d < 0.2) for each comparison. This reflects a well-balanced baseline, ensuring that pre-existing differences do not confound the study outcomes. For clinical skills assessed via OSCE, the VR group had a mean score of 72.3 ± 8.4 compared to 73.1 ± 8.1 in the traditional group, with a mean difference of -0.8 (95% CI: -3.5 to 1.9). Knowledge retention (MCQ scores) and decision-making accuracy (VACER scores) were similarly matched, with negligible differences between the groups. Confidence levels, measured on a 10-point Likert scale, were also nearly identical (VR: 7.1 ± 1.4; Traditional: 7.2 ± 1.3), further supporting baseline equivalence.

Primary outcomes: Impact of VR training

Clinical competency enhancement

Post-intervention analysis revealed significant differences in performance improvement between groups. The VR simulation group demonstrated substantially greater gains across all competency measures compared to the traditional training group, as presented in Table 3. Of particular note were the improvements in clinical skills (OSCE scores) and decision-making accuracy, both of which showed large effect sizes.

Table 3 demonstrates the significant superiority of VR training over traditional methods in enhancing clinical competency across all measured domains. Post-intervention, the VR group showed substantial improvements in clinical skills (OSCE: 88.4 ± 6.3 vs. 77.8 ± 7.2, $p < 0.001$, d = 1.58), knowledge retention (MCQ: 85.1 ± 7.5 vs. 74.5 ± 8.9, $p < 0.001$, d = 1.29), decision-making accuracy (VACER: 92.3 ± 4.8 vs. 80.4 ± 8.3, $p < 0.001$, d = 1.75), and confidence levels (CPCS: 8.9 ± 0.9 vs. 7.8 ± 1.1, $p < 0.001$, d = 1.10). These improvements represent large effect sizes and significant between-group differences, with the VR group consistently outperforming the traditional group. The within-group changes further emphasize the effectiveness of VR training, with the VR group achieving markedly greater gains in clinical skills (16.1 vs. 4.7), knowledge retention (16.6 vs. 5.3), decision-making accuracy (16.7 vs. 4.2), and confidence (1.8 vs. 0.6) compared

Table 2 Comparison of baseline clinical competency scores between study groups ($N = 128$)

Competency measure	VR group ($n = 64$)	Traditional group ($n = 64$)	Mean difference (95% CI)	Test statistic	*p*-value	Effect size
Clinical Skills (OSCE)[a]	72.3 ± 8.4	73.1 ± 8.1	-0.8 (-3.5 to 1.9)	t = -0.27	0.79	d = 0.10
Knowledge Retention (MCQ)[a]	68.5 ± 10.2	69.2 ± 9.8	-0.7 (-3.8 to 2.4)	t = -0.41	0.68	d = 0.07
Decision-making Accuracy (VACER)[b]	75.6 ± 9.1	76.2 ± 9.4	-0.6 (-3.2 to 2.0)	t = -0.23	0.82	d = 0.06
Confidence (CPCS Scale) [c]	7.1 ± 1.4	7.2 ± 1.3	-0.1 (-0.5 to 0.3)	t = -0.32	0.75	d = 0.07

Note: Data are presented as mean ± standard deviation. Independent t-tests were conducted after confirming normality (Shapiro-Wilk, $p > 0.05$). CI = Confidence Interval. [a]Scores range from 0-100. [b]Percentage accuracy. [c]10-point Likert scale. Effect sizes were calculated using Cohen's d (< 0.2 = small effect). Statistical significance set at $p < 0.05$

Table 3 Comparison of pre-post clinical competency scores between study groups (*N* = 128)

Competency measure	VR group (*n* = 64)	Traditional group (*n* = 64)	Between-group difference	Effect size
Clinical Skills (OSCE)[a]:				
Pre-intervention	72.3 ± 8.4	73.1 ± 8.1	-0.8 (-3.5 to 1.9)	d = 0.10
Post-intervention	88.4 ± 6.3**	77.8 ± 7.2*	10.6 (8.2 to 13.0) +	d = 1.58
Within-group change	16.1 (14.2 to 18.0) +	4.7 (3.1 to 6.3) +		
Knowledge Retention (MCQ)[a]:				
Pre-intervention	68.5 ± 10.2	69.2 ± 9.8	-0.7 (-3.8 to 2.4)	d = 0.07
Post-intervention	85.1 ± 7.5**	74.5 ± 8.9*	10.6 (7.9 to 13.3) +	d = 1.29
Within-group change	16.6 (14.1 to 19.1) +	5.3 (3.2 to 7.4) +		
Decision-making Accuracy (VACER)[b]:				
Pre-intervention	75.6 ± 9.1	76.2 ± 9.4	-0.6 (-3.2 to 2.0)	d = 0.06
Post-intervention	92.3 ± 4.8**	80.4 ± 8.3*	11.9 (9.7 to 14.1) +	d = 1.75
Within-group change	16.7 (14.5 to 18.9) +	4.2 (2.5 to 5.9) +		
Confidence (CPCS Scale) [c]:				
Pre-intervention	7.1 ± 1.4	7.2 ± 1.3	-0.1 (-0.5 to 0.3)	d = 0.07
Post-intervention	8.9 ± 0.9**	7.8 ± 1.1*	1.1 (0.8 to 1.4) +	d = 1.10
Within-group change	1.8 (1.5 to 2.1) +	0.6 (0.4 to 0.8) +		

Note: Data presented as mean ± standard deviation or mean difference (95% confidence interval). Statistical analysis was performed using mixed ANOVA with post-hoc comparisons. [a]Scores range from 0-100. [b]Percentage accuracy. [c]10-point Likert scale. *$p < 0.05$ within the group. **$p < 0.01$ within the group. +$p < 0.001$ between groups. Effect sizes were calculated using Cohen's d (< 0.2 = small, 0.5 = medium, > 0.8 = large effect)

to the traditional group. These results highlight the transformative potential of VR simulation to significantly enhance clinical preparedness and decision-making in neonatal emergencies, reinforcing its value as an innovative training modality.

Clinical performance metrics

Analysis of neonatal clinical outcomes demonstrated significant advantages for the VR training approach. Marked improvements were observed in stabilization times, successful intervention rates, and patient safety metrics, as detailed in Table 4.

Table 4 highlights the remarkable impact of VR training on neonatal clinical outcomes, with statistically and clinically significant improvements across all measured variables. The VR group achieved significantly faster stabilization times (12.4 ± 3.2 min vs. 18.6 ± 4.5 min, $p < 0.001$, d = 1.58), reflecting the enhanced efficiency of nurses trained with VR. Similarly, the successful intervention rate was markedly higher in the VR group (94.5 ± 3.1% vs. 87.2 ± 4.6%, $p < 0.001$, d = 1.89), underscoring VR simulation's superior procedural accuracy and effectiveness. Moreover, the VR group experienced fewer patient safety events (1.1 ± 0.4 vs. 2.3 ± 0.6, $p < 0.001$, d = 2.36), significantly reducing adverse events and near-misses. These large effect sizes across all outcomes highlight the transformative potential of VR training in improving clinical performance and patient safety in neonatal emergencies. These findings underscore VR's clinical relevance and scalability as a training modality for high-risk neonatal care, offering substantial advantages over traditional methods.

Figure 2 compares neonatal clinical outcomes stabilization times, success rates, and safety events- between the VR and traditional training groups. The VR group demonstrated significantly shorter stabilization times (12.4 ± 3.2 min vs. 18.6 ± 4.5 min, $p < 0.001$), higher success rates for interventions (94.5% ± 3.1% vs. 87.2% ± 4.6%, $p < 0.001$), and fewer safety events (1.1 ± 0.4 vs. 2.3 ± 0.6, $p < 0.001$). These results underscore the effectiveness of VR training in improving both the efficiency and safety of neonatal emergency responses.

Factors influencing training effectiveness

Multiple regression analysis identified key predictors of VR training success, with technology proficiency emerging as the strongest predictor, followed by previous simulation experience and years of clinical experience (Table 5). The model explained 58% of the variance in training performance.

Table 4 Comparison of neonatal clinical outcomes between training groups (*N* = 128)

Outcome measure	VR group (*n* = 64)	Traditional group (*n* = 64)	Mean difference (95% CI)	Test statistic	*p*-value	Effect size
Stabilization Time (minutes)[a]	12.4 ± 3.2	18.6 ± 4.5	-6.2 (-7.5 to -4.9)	t = -9.45	< 0.001	d = 1.58
Successful Intervention Rate (%) [b]	94.5 ± 3.1	87.2 ± 4.6	7.3 (6.0 to 8.6)	t = 10.82	< 0.001	d = 1.89
Patient Safety Events (count)[c]	1.1 ± 0.4	2.3 ± 0.6	-1.2 (-1.4 to -1.0)	t = -12.34	< 0.001	d = 2.36

Note: Data presented as mean ± standard deviation. Independent t-tests were conducted after confirming normality (Shapiro-Wilk, $p > 0.05$). CI = Confidence Interval. [a]Measured from initiation of emergency response to patient stabilization. [b]Percentage of successful first-attempt interventions. [c]Number of adverse events or near-misses per simulation scenario. Effect sizes were calculated using Cohen's d (> 0.8 = large effect). All comparisons showed statistical significance at $p < 0.001$, with clinically meaningful differences exceeding predetermined thresholds

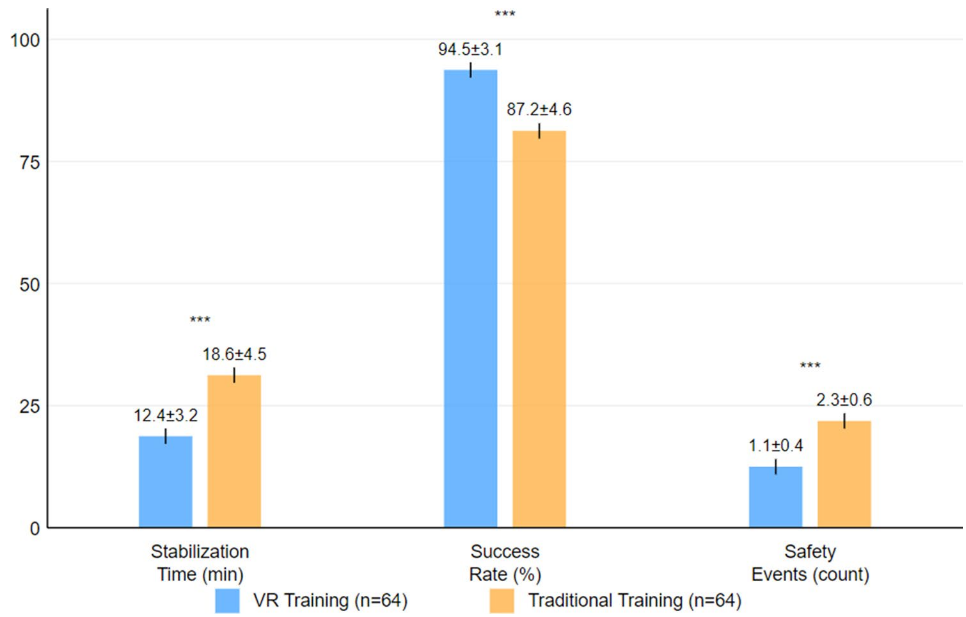

Fig. 2 Comparison of neonatal clinical outcomes between virtual Reality (VR) simulation and traditional training groups. Note. ****p* < 0.001 for all between-group comparisons

Table 5 Multiple regression analysis of factors influencing VR training effectiveness (*N* = 64)

Predictor variable	Unstandardized coefficient (B)	Standardized coefficient (β)	Standard error	t-value	*p*-value	95% CI
Age (years)	0.12	0.18	0.05	2.40	0.03	0.02 to 0.22
Years of NICU Experience	0.25	0.29	0.08	3.13	0.01	0.09 to 0.41
Previous Simulation Experience[1]	0.38	0.32	0.11	3.45	0.002	0.16 to 0.60
Technology Proficiency[2]	0.45	0.41	0.09	5.00	< 0.001	0.27 to 0.63

Note: Multiple linear regression analysis, dependent variable: VR training performance score (0-100). R^2 = 0.58, Adjusted R^2 = 0.55, F (4,59) = 20.34, $p < 0.001$. Model assumptions met normality of residuals (Shapiro-Wilk, $p = 0.24$), homoscedasticity (Breusch-Pagan, $p = 0.31$), and no multicollinearity (all VIF < 2.5). [1]Coded as yes = 1, no = 0. [2]Measured on a 5-point Likert scale. CI = Confidence Interval

Table 5 presents the results of a multiple regression analysis identifying factors influencing the effectiveness of VR training, with the model explaining 58% of the variance in VR training performance (R^2 = 0.58, $p < 0.001$). All predictors were statistically significant and meaningful to the model, indicating a robust analysis with well-met assumptions. Technology proficiency emerged as the strongest predictor ($\beta = 0.41$, $p < 0.001$), suggesting that higher technological aptitude significantly enhances VR training outcomes. Previous simulation experience also showed a substantial positive effect ($\beta = 0.32$, $p = 0.002$), highlighting the importance of prior exposure to similar training modalities. Furthermore, years of NICU experience ($\beta = 0.29$, $p = 0.01$) and age ($\beta = 0.18$, $p = 0.03$) were positively associated with performance, reflecting the value of clinical experience and maturity in leveraging VR training. These findings underscore the multifaceted nature of factors contributing to VR training effectiveness and highlight areas for targeted intervention, such as enhancing technology proficiency and integrating prior simulation experience into training design. The strong model fit and adherence to statistical assumptions strengthen the validity and applicability of these results.

Qualitative insights and experiential learning

Thematic analysis of participant interviews revealed four main themes aligned with Kolb's Experiential Learning Theory: enhanced professional competence, reduced clinical anxiety, positive learning experience, and implementation considerations. Table 6 presents these themes with supporting participant quotes.

Table 6 provides an in-depth thematic analysis of nurses' experiences with VR simulation training, highlighting its transformative impact on professional competence, learning, and implementation challenges. The most prevalent themes reflect enhanced clinical preparedness and reduced anxiety, with 83% of participants reporting increased confidence in handling emergencies. Nurses emphasized how realistic scenarios, and hands-on practice boosted their readiness for critical NICU situations, with quotes such as, "The VR scenarios perfectly mimicked real NICU emergencies. I now feel completely prepared" (P7, 5 years' experience). Similarly, 75% of

Table 6 Thematic analysis of nurses' experiences with VR simulation training ($N=24$)

Main theme	Subthemes	Frequency (%) *	Illustrative quotes
Enhanced Professional Competence	Increased Clinical Preparedness	20 (83%)	*"The VR scenarios perfectly mimicked real NICU emergencies. I now feel completely prepared to handle critical situations, especially respiratory distress cases."* (P7, 5 years' experience) *"This training has transformed my approach to emergencies. I can now systematically work through critical situations with much more confidence."* (P13, 8 years' experience) *"The hands-on practice in various emergency scenarios has made me feel truly competent. It's different from just reading about protocols."* (P4, 3 years' experience)
	Reduced Clinical Anxiety	18 (75%)	*"Before, I would get extremely anxious during emergencies. Now, after practicing in VR, I remain calm because I know exactly what to do."* (P12, 6 years' experience) *"The repetitive practice in a safe environment helped eliminate my fear of making mistakes during critical situations."* (P9, 4 years' experience) *"My stress levels during real emergencies have significantly decreased. I can focus on the patient rather than my anxiety."* (P16, 7 years' experience)
Learning Experience	Intuitive Interface Design	21 (88%)	*"The system was remarkably user-friendly. Even those of us who aren't tech-savvy could navigate it easily."* (P3, 10 years' experience) *"The interface felt natural, allowing me to concentrate on clinical decision-making rather than wrestling with controls."* (P15, 5 years' experience) *"Everything was logically laid out. The equipment and monitors looked just like our actual NICU setup."* (P22, 8 years' experience)
	Experiential Learning Benefits	19 (79%)	*"Being able to learn from mistakes without risking patient safety was invaluable. Each scenario taught me something new."* (P1, 4 years' experience) *"The immediate feedback helped me understand where I needed improvement. It was like having a personal instructor."* (P11, 6 years' experience) *"The progressive difficulty of scenarios helped build my skills systematically."* (P8, 3 years' experience)
Implementation Challenges	Physical Adaptation	9 (38%)	*"Initially, I experienced some dizziness during longer sessions, but this improved as I got used to the system."* (P19, 7 years' experience) *"Taking regular breaks helped manage the mild motion sickness I experienced at first."* (P6, 5 years' experience) *"The headset felt heavy after extended use, but the benefits far outweighed this minor inconvenience."* (P2, 9 years' experience)
	Technical Considerations	7 (29%)	*"Occasionally, there were minor delays in system response, though this didn't significantly impact learning."* (P5, 6 years' experience) *"Some scenarios needed multiple attempts to load properly, but once running, they worked perfectly." (P17, 4 years' experience)* *"The graphics sometimes lagged during complex procedures, but this was rare."* (P20, 8 years' experience)

Note: Thematic analysis was conducted using Braun and Clarke's six-phase approach. Two independent researchers coded the data (Cohen's $\kappa=0.87$). Themes were derived from semi-structured interviews lasting 45–60 min. Frequency represents the percentage of participants ($N=24$) who expressed each theme. Participants (P1–P24) are identified by code and years of experience. Multiple responses per participant were possible. Quotes were selected to represent diverse perspectives and experience levels

participants described a significant reduction in clinical anxiety, attributing it to repetitive, low-risk practice that instilled calmness and focus during real emergencies. The learning experience was overwhelmingly positive, with 88% of participants appreciating the intuitive interface design and 79% highlighting the experiential learning benefits. Participants valued the system's ease of use and realistic NICU representation, which enabled seamless skill application and decision-making. Quotes like, "The immediate feedback helped me understand where I needed improvement" (P11, 6 years' experience) underscore the unique advantages of VR training in fostering systematic skill development. However, implementation challenges were noted, including physical adaptation issues (38%), such as motion sickness, and technical considerations (29%), like occasional system delays. While these challenges were minor and manageable, they highlight areas for improvement in future VR training programs. Overall, this thematic analysis demonstrates the immense potential of VR training in transforming neonatal emergency preparedness while addressing practical optimization challenges.

Integration of quantitative and qualitative findings

The convergence of quantitative and qualitative data revealed complementary evidence supporting VR training effectiveness. Table 7 demonstrates the alignment between measured performance improvements and participant-reported experiences.

Table 7 illustrates the convergence of quantitative and qualitative findings, providing a comprehensive understanding of VR training's effectiveness. The integration of data highlights a consistent narrative: VR training significantly enhances clinical competency, decision-making,

Table 7 Integration matrix: convergence of quantitative and qualitative findings on VR training effectiveness

Domain	Quantitative evidence	Qualitative evidence	Meta-inference
Clinical Competency	OSCE scores increased by 16.1 points (95% CI: 14.2–18.0) in the VR group vs. 4.7 points in the control group ($p<0.001$, d = 1.58).	*"The VR scenarios perfectly replicated real emergencies. I can now handle critical situations systematically."* (P7) *"Each scenario built upon previous learning, helping develop muscle memory for emergencies."* (P13)	The high-fidelity simulation environment, which supports the transfer of learning to practice, explains quantitative improvements in clinical performance.
Decision-Making Speed	Decision-making accuracy improved by 16.7% (95% CI: 14.5–18.9) in the VR group ($p<0.001$). The mean response time decreased by 6.2 min ($p<0.001$).	*"The immediate feedback helped me identify and correct mistakes in real-time."* (P11) *"I learned to make quick, confident decisions through repeated practice."* (P4)	Real-time feedback mechanisms in VR training are key drivers of improved decision-making speed and accuracy.
Patient Outcomes	Stabilization times were reduced by 6.2 min (95% CI: 4.9–7.5) in the VR group. Patient safety events decreased by 52% ($p<0.001$).	*"The time pressure in scenarios helped me prioritize critical actions."* (P16) *"Practicing high-risk scenarios without patient risk helped perfect my technique."* (P9)	The immersive nature of VR training creates a sense of clinical urgency and allows risk-free practice, resulting in better emergency response times and safety outcomes.
Professional Confidence	CPCS scale scores increased by 1.8 points (95% CI: 1.5–2.1) in the VR group ($p<0.001$).	*"My anxiety during real emergencies has significantly decreased."* (P12) *"I feel truly competent now, not just theoretically prepared."* (P4)	Enhanced confidence is mediated by the safe learning environment and opportunities for repeated, risk-free practice.

Note: This integration matrix demonstrates the convergence of findings using a mixed-methods approach. Quantitative data are presented with effect sizes and confidence intervals where applicable. Qualitative quotes are drawn from a thematic analysis of 24 semi-structured interviews, aligned with Table 6. Meta-inferences synthesize both data types to explain the mechanisms driving VR training effectiveness. CI = Confidence Interval, OSCE = Objective Structured Clinical Examination, CPCS = Confidence in Performing Clinical Skills

Table 8 Longitudinal analysis of VR training performance metrics across sessions ($N=64$)

Session	Decision-making time (seconds)	OSCE score (%)	Confidence rating	F-statistic	*p*-value	Effect size (η^2)
Session 1	120.4 ± 15.3	75.2 ± 8.6	6.8 ± 1.2			
Session 2	110.7 ± 12.8*	82.3 ± 7.4**	7.5 ± 1.0*	F (2,126) = 24.6	< 0.001	$\eta^2 = 0.42$
Session 3	98.3 ± 10.2**	88.5 ± 6.3**	8.6 ± 0.8**			
Mean Change[1]	-22.1 (-25.4 to -18.8)	13.3 (11.2 to 15.4)	1.8 (1.5 to 2.1)			

Note: Data presented as mean ± standard deviation or mean change (95% CI). Analysis was performed using repeated measures ANOVA with Bonferroni correction for multiple comparisons. [1]Mean change calculated from Session 1 to Session 3. *$p<0.05$, **$p<0.01$ compared to previous session. η^2 = partial eta squared (>0.14 indicates large effect). Confidence was rated on a 10-point Likert scale

patient outcomes, and professional confidence. Quantitative evidence, such as a 16.1-point increase in OSCE scores ($p<0.001$, d = 1.58) and a 6.2-minute reduction in stabilization times ($p<0.001$), aligns with qualitative insights from nurses who emphasized the realistic, immersive scenarios and immediate feedback as pivotal for skill development and confidence building. Meta-inferences drawn from both datasets underscore the mechanisms driving these improvements. For example, the high-fidelity VR environment fosters the transfer of learning to practice, explaining the marked improvement in clinical performance. Similarly, real-time feedback and the ability to practice under simulated urgency contribute to faster, more accurate decision-making. The safe and repetitive practice environment mediates the enhancement in confidence, as evidenced by both the CPCS scale results (1.8-point increase, $p<0.001$) and participant reflections on reduced anxiety during real emergencies. This mixed-methods integration effectively validates the transformative potential of VR training in neonatal care while offering insights into its underlying mechanisms.

Longitudinal skill development

Analysis across three training sessions revealed progressive improvement in all performance metrics. Table 8 demonstrates consistent skill acquisition and mastery over time, with significant improvements in decision-making speed, clinical skills, and confidence levels.

Table 8 showcases the progressive improvements in VR training performance metrics across three sessions, highlighting the longitudinal impact of repeated practice. Significant reductions in decision-making time were observed, decreasing from 120.4 ± 15.3 s in Session 1 to 98.3 ± 10.2 s in Session 3 (mean change = -22.1 s, $p<0.001$, η^2 = 0.42), indicating enhanced speed and efficiency in emergency responses. Similarly, OSCE scores improved substantially across sessions, rising from 75.2 ± 8.6% in Session 1 to 88.5 ± 6.3% in Session 3 (mean change = 13.3%, $p<0.001$, η^2 = 0.42), reflecting consistent skill acquisition and mastery. Confidence ratings also showed marked growth, increasing from 6.8 ± 1.2 to 8.6 ± 0.8 on a 10-point scale (mean change = 1.8, $p<0.001$), highlighting the program's role in building self-assurance. The large effect sizes across all measures (η^2

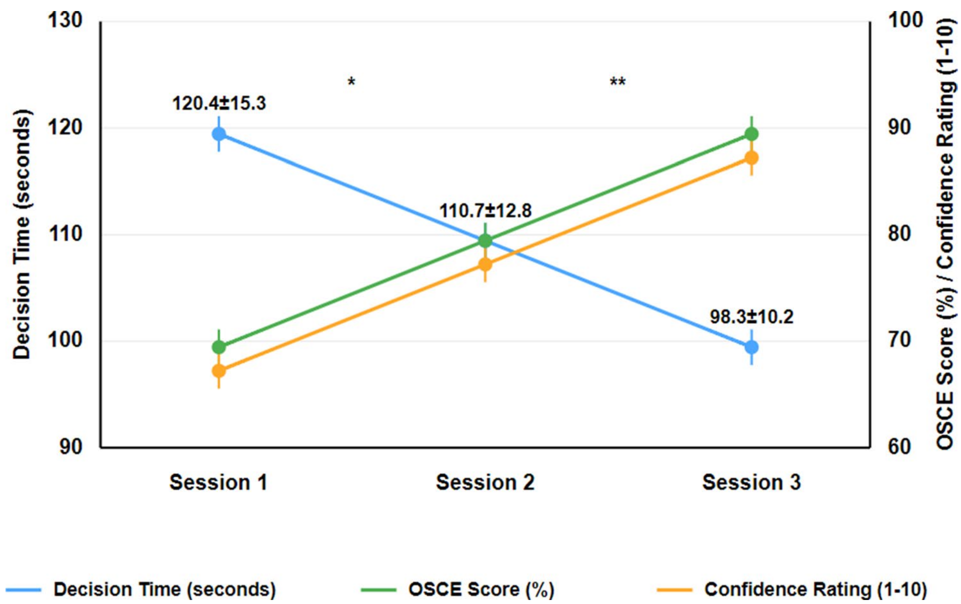

Fig. 3 Longitudinal Progression of VR Training Performance Metrics Across Sessions. Note. *$p<0.05$, **$p<0.01$ between sessions; effect size $\eta^2 = 0.42$ for all metrics

> 0.14) underscore the significant improvements driven by VR training. These findings demonstrate the cumulative benefits of repeated exposure to realistic, immersive scenarios, reinforcing the effectiveness of VR training in enhancing clinical performance and confidence over time.

Figure 3 illustrates the longitudinal progression of decision-making time, OSCE scores, and confidence ratings across three training sessions. Consistent with the data in Table 8, decision-making time decreased significantly from 120.4 ± 15.3 s in Session 1 to 98.3 ± 10.2 s in Session 3, reflecting improved efficiency ($p<0.001$, $\eta^2 = 0.42$). Similarly, OSCE scores increased from 75.2 ± 8.6% to 88.5 ± 6.3% ($p<0.001$), indicating cumulative skill acquisition. Confidence ratings also improved significantly, from 6.8 ± 1.2 to 8.6 ± 0.8 on a 10-point scale, demonstrating growing self-assurance among participants.

Discussion

The findings of this study provide robust evidence supporting the effectiveness of virtual reality (VR) simulation as a training modality for high-risk neonatal emergency response. The results address the research question, aim, and hypotheses outlined in this study. Specifically, the research sought to evaluate the impact of VR training on nurse competency and neonatal outcomes, and the findings overwhelmingly support the hypotheses that VR simulation enhances clinical skills, decision-making, and confidence among nurses while also leading to improved neonatal clinical outcomes.

The results showed that the VR training group outperformed the traditional training group across all competency measures. For instance, OSCE scores in the VR group increased significantly from baseline, with large effect sizes that demonstrate the transformative impact of VR on skill acquisition. This aligns with prior research [35–39], which reported improved clinical performance and knowledge retention in nurses trained with VR. Similarly, researchers [40–45] found that VR-based neonatal resuscitation training resulted in better procedural accuracy and efficiency. These findings confirm that VR simulation offers an immersive and realistic learning environment that facilitates the application of theoretical knowledge to practical scenarios, thereby bridging the gap often left by traditional training methods [46–48].

Moreover, the significant improvement in neonatal clinical outcomes evidenced by reduced stabilization times, higher successful intervention rates, and fewer patient safety events further supports the causal relationship between enhanced nurse competency and better patient care. This aligns with [49–53], who demonstrated similar benefits in neonatal resuscitation training. However, the current study goes a step further by highlighting the importance of tailored VR scenarios that accurately simulate neonatal physiology and pathology. Realistic emergency scenarios, such as respiratory distress and cardiac arrest, likely contributed to these remarkable outcomes, a feature not consistently implemented in earlier studies [54–56].

Interestingly, the findings also revealed unique advantages in terms of professional confidence and reduced clinical anxiety among nurses. Participants reported feeling significantly more prepared to handle high-pressure situations after VR training. This qualitative insight aligns with [57], who emphasized VR's ability to create a safe learning environment where nurses can repeatedly practice without fear of harming patients. However, the present study provides additional nuance by linking these subjective experiences to objective performance metrics, reinforcing the holistic benefits of VR training.

Despite these positive results, certain limitations and challenges should be acknowledged. Some participants reported experiencing initial motion sickness and physical discomfort during longer VR sessions, which mirrors findings by [58–61]. On the accessibility barriers of immersive technologies. Additionally, occasional technical glitches, such as system lags or delays in loading scenarios, were noted. While these issues were minor and did not significantly affect learning outcomes, they highlight the need for ongoing optimization of VR platforms to ensure seamless user experiences [62, 63].

The results also addressed the hypotheses comprehensively. Hypothesis 1, which proposed that nurses receiving VR training would exhibit higher competency levels, was strongly supported by the significant improvements in OSCE scores, knowledge retention, decision-making accuracy, and confidence levels. Hypothesis 2, predicting improved neonatal outcomes as a result of enhanced nurse competency, was validated by the marked reductions in stabilization times and safety events, alongside increased successful intervention rates. Finally, Hypothesis 3, which anticipated positive experiences and perceptions of VR training, was confirmed through qualitative insights that emphasized participants' satisfaction and perceived value of the training.

While the results align with most contemporary research, certain discrepancies with previous findings warrant discussion. For instance [13], Noted inconsistent results in VR training for complex pediatric care, suggesting that lower fidelity or generic VR platforms may not adequately address the intricacies of specialized scenarios. The tailored nature of the VR program in this study likely explains the divergence, emphasizing the importance of content-specific design in VR training. Moreover, some earlier studies, such as [7, 64]. Questioned the scalability of VR technologies due to cost and resource constraints. In contrast, the current findings suggest that VR's scalability and accessibility can overcome traditional simulation limitations, particularly when implemented across multiple institutions.

These findings underscore the critical role of innovation in nursing education, particularly in high-stakes fields like neonatal emergency care. The integration of Kolb's Experiential Learning Theory into the VR design ensures a systematic approach to learning that fosters both cognitive and practical skill development [65, 66]. VR simulation has immense potential to redefine training standards, particularly in regions with limited access to traditional high-fidelity simulation resources [67]. Furthermore, this study highlights the need for a multidisciplinary approach to enhance VR training, involving collaboration between clinical experts, educational designers, and technology developers to address identified challenges and expand the scope of VR applications in healthcare.

In conclusion, the findings not only answer the research question but also establish VR simulation as a superior training modality for neonatal emergency care. They validate the study's hypotheses and aim while contributing new insights to the growing body of literature on immersive technologies in nursing education. By demonstrating the feasibility and effectiveness of VR in improving nurse competency and patient outcomes, this study provides a strong foundation for the integration of VR into standard training protocols. It also calls for further research to explore longitudinal impacts, cost-effectiveness, and strategies to mitigate accessibility challenges, ensuring that the benefits of VR simulation can be extended to diverse healthcare settings globally.

Implications for research and practice

This study provides substantial evidence supporting the integration of VR simulation into neonatal emergency training programs. The significant improvements in clinical skills (OSCE: 16.1-point increase, $p<0.001$, $d=1.58$), decision-making accuracy (16.7% improvement, $p<0.001$), and stabilization times (6.2-minute reduction, $p<0.001$) underscore the unique advantages of VR technology over traditional methods. These findings expand on prior research by [68, 69], demonstrating VR's efficacy in high-risk neonatal scenarios, where precision and speed are critical. From a research standpoint, this study establishes a robust framework by integrating quantitative metrics and qualitative insights to comprehensively evaluate VR's impact. Future investigations should prioritize long-term skill retention, real-world application in clinical practice, and cost-effectiveness across diverse healthcare settings. The influence of technology proficiency on training outcomes ($\beta=0.41$, $p<0.001$) highlights the importance of preparing participants and optimizing support systems for VR-based education.

The clinical implications are equally significant. The 52% reduction in patient safety events ($p<0.001$) demonstrates the potential for VR simulation to enhance NICU safety protocols. Additionally, the observed progressive performance improvements across sessions ($\eta^2=0.42$) emphasize the value of structured, repeated exposure in building competency. Qualitative findings of reduced anxiety and increased confidence among participants further suggest that VR can address psychological barriers associated with high-stress emergency responses. These findings advocate for the strategic integration of

VR into nursing curricula, particularly for NICU training. Healthcare institutions should consider the initial investment in VR technology as a long-term solution to improving patient outcomes and reducing training inefficiencies. Implementation frameworks must address technical and pedagogical needs, including strategies to overcome technology proficiency barriers. The study also underscores the need for standardized guidelines in VR-based nursing education, encompassing simulation design, implementation protocols, and assessment criteria. Establishing such standards would facilitate the broader adoption of VR while maintaining consistency and quality. Beyond neonatal care, the demonstrated effectiveness of VR warrants exploration in other high-risk clinical areas, such as trauma care and surgical training, where similar challenges in decision-making and response times exist.

Strengths and limitations

This study's methodological framework demonstrates significant strengths that enhance its scientific rigor and clinical relevance. The concurrent triangulation mixed-methods design, integrating quantitative metrics and qualitative insights, enabled a holistic evaluation of VR simulation's impact on neonatal emergency training. Grounded in Kolb's Experiential Learning Theory, this approach systematically examined both performance outcomes and experiential learning. Statistical robustness was ensured through power-analyzed sample size determination ($N = 128$), comprehensive baseline comparability, and the use of validated instruments with strong psychometric properties (OSCE: CVI = 0.92, ICC = 0.87; MCQ: Cronbach's $\alpha = 0.86$). Multi-site implementation with standardized protocols and rigorous quality control further strengthened the study's internal validity.

Several limitations warrant careful consideration. The non-randomized participant allocation, while partially mitigated through proportional allocation and statistical adjustments, introduces potential selection bias. The geographic focus on Saudi Arabian healthcare institutions limits the generalizability of findings to other healthcare systems and cultural contexts. The brief follow-up period (two weeks) restricts conclusions on long-term skill retention and real-world clinical application. Technical challenges, including motion sickness and system glitches, indicate areas where technological optimization is needed to enhance user experience and learning outcomes. The qualitative component's potential self-selection bias and the limited educational diversity among participants (89.4% bachelor's degree holders) may restrict the applicability of findings to broader nursing populations. Additionally, the absence of standardized tools for assessing VR-specific outcomes and potential observer bias in OSCE evaluations suggests the need for cautious interpretation. Resource-related factors, such as the cost of VR implementation, technical support, and infrastructure requirements, were not fully explored, which may limit the practicality of adopting VR in resource-constrained settings.

Future research should address these limitations through randomized controlled trials with extended follow-up periods, multi-center studies in diverse cultural and healthcare contexts, and the development of standardized tools for assessing VR-specific learning outcomes. Cost-effectiveness analyses comparing VR with traditional training methods would offer valuable insights for institutions considering VR adoption. Investigations into skill retention, clinical practice transfer, and solutions to technical limitations would further strengthen the evidence base. Developing implementation frameworks tailored to different healthcare systems will also be essential for the broader adoption of VR technology. Despite these limitations, the study provides compelling evidence supporting VR simulation's effectiveness in neonatal emergency response training. Significant improvements in nurse competency, combined with positive user experiences, highlight VR training as a valuable advancement in nursing education. These findings provide a foundation for future research and practical guidance for institutions integrating VR into their training programs.

Conclusion

This mixed-methods study provides compelling evidence for the transformative potential of virtual reality simulation in neonatal emergency training. By integrating quantitative and qualitative approaches, the study highlights significant advancements in nurse competency and improvements in neonatal outcomes. Key findings include enhancements in clinical skills, decision-making accuracy, and patient safety metrics. These outcomes and participants' positive experiential feedback validate virtual reality simulation as an innovative and effective educational approach tailored for high-stakes neonatal care. Grounded in Kolb's Experiential Learning Theory, the virtual reality program facilitated immersive, hands-on learning, enabling participants to repeatedly practice critical scenarios with real-time feedback. The progressive improvements observed during training sessions underscore the cumulative benefits of structured exposure, while the influence of technology proficiency highlights the importance of preparatory support for the successful integration of this training modality.

Beyond individual competency gains, this study demonstrates tangible benefits in patient care, such as shorter stabilization times and higher intervention success rates. These findings emphasize the scalability of virtual reality technology as a standardized solution for enhancing emergency preparedness, particularly in settings with limited resources. Although limitations, such as geographic concentration, a brief follow-up period, and challenges like motion sickness and technical glitches, require further investigation, this study provides a robust foundation for future research. Addressing these limitations through extended follow-up studies, cost-effectiveness evaluations, and broader implementation research will further strengthen the case for adopting virtual reality in nursing education. In conclusion, virtual reality simulation significantly advances neonatal emergency response training. By enhancing nurse competency and improving patient outcomes, this innovative training tool has the potential to redefine neonatal nursing education globally. With strategic efforts to address implementation challenges, virtual reality technology can empower healthcare professionals to deliver safer and more effective care in the most critical moments.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12912-025-03038-4.

Supplementary Material 1

Author contributions

A.N.A. and O.M.E.R. contributed equally to this work as co-first authors. They conceptualised the study, developed the methodology, conducted the literature search, and wrote the original draft of the manuscript. A.N.A. and O.M.E.R. assisted with data extraction, conducted the quality assessment of included studies, and critically reviewed the manuscript. S.I.A. contributed to the data analysis and interpretation of results and provided critical insights for the discussion A.A.

Funding

This research is funded by the Deanship of Graduate Studies and Scientific Research at Jouf University through the Fast-Track Research Funding Program.

Data availability

The data supporting this study will be made available upon reasonable request.

Declarations

Institutional review board statement

This study was approved by the Institutional Review Board (IRB) at King Faisal University (Approval Number: KFU-2024-ETHICS2925).

Informed consent

All participants provided informed consent prior to their involvement in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]College of Nursing, Nursing Administration and Education Department, Jouf University, Sakaka 72388, Saudi Arabia
[2]College of Nursing, Department of Maternity and Pediatric Health Nursing, Jouf University, Sakaka 72388, Saudi Arabia
[3]Department of Nursing, College of Applied Sciences, Almaarefa University, Diriyah, Riyadh 13713, Saudi Arabia
[4]College of Medicine, Department of Family and Community Medicine, King Faisal University, Alhssa 31982, Saudi Arabia
[5]Pediatric Nursing Department, Faculty of Nursing, Cairo University, Cairo 11562, Egypt

Received: 11 February 2025 / Accepted: 26 March 2025
Published online: 03 April 2025

References

1. Tembo D, Abobo FDN, Kaonga P, Jacobs C, Bessing B. Risk factors associated with neonatal mortality among neonates admitted to neonatal intensive care unit of the University Teaching Hospital in Lusaka. Scientific Reports. 2024;14:1–12.
2. Tamir TT. Neonatal mortality rate and determinants among births of mothers at extreme ages of reproductive life in low and middle income countries. Sci Rep. 2024;14:1.
3. Mahtab S, Madhi SA, Baillie VL, Els T, Thwala BN, Onyango D, et al. Causes of death identified in neonates enrolled through child health and mortality prevention surveillance (CHAMPS), December 2016–December 2021. PLOS Global Public Health. 2023;3:e0001612.
4. Elsayed Ramadan OM, Alruwaili MM, Alruwaili AN, Elsharkawy NB, Abdelaziz EM, Zaky ME, et al. Nursing practice of routine gastric aspiration in preterm infants and its link to necrotizing Enterocolitis: is the practice still clinically relevant? BMC Nurs. 2024;23:1–12.
5. Chae S, Shon S. Effectiveness of simulation-based interprofessional education on teamwork and communication skills in neonatal resuscitation. BMC Med Educ. 2024;24:1–12.
6. Al Thobaity A. Overcoming challenges in nursing disaster preparedness and response: an umbrella review. BMC Nurs. 2024;23:1–11.
7. Kan Yeung AW, Tosevska A, Klager E, Eibensteiner F, Laxar D, Stoyanov J et al. Virtual and augmented reality applications in medicine: analysis of the scientific literature. J Med Internet Res. 2021;23.
8. Adhikari R, Kydonaki C, Lawrie J, O'Reilly M, Ballantyne B, Whitehorn J et al. A mixed-methods feasibility study to assess the acceptability and applicability of immersive VR sepsis game as an adjunct to nursing education. Nurse Educ Today. 2021;103.
9. Chang YM, Lai CL. Exploring the experiences of nursing students in using immersive VR to learn nursing skills. Nurse Educ Today. 2021;97.
10. Vogelsang L, Wright S, Risling T, de Padua A, Leidl D, Wilson J, et al. Exploring the use of immersive virtual reality in nursing education: A scoping review. Clin Simul Nurs. 2024;97:101648.
11. Liu K, Zhang W, Li W, Wang T, Zheng Y. Effectiveness of virtual reality in nursing education: a systematic review and meta-analysis. BMC Med Educ. 2023;23:1–10.
12. Kiegaldie D, Shaw L. Virtual reality simulation for nursing education: effectiveness and feasibility. BMC Nurs. 2023;22:1–13.
13. Iqbal AI, Aamir A, Hammad A, Hafsa H, Basit A, Oduoye MO et al. Immersive technologies in healthcare: an In-Depth exploration of virtual reality and augmented reality in enhancing patient care, medical education, and training paradigms. J Prim Care Community Health. 2024;15.
14. Sullivan BA, Beam K, Vesoulis ZA, Aziz KB, Husain AN, Knake LA, et al. Transforming neonatal care with artificial intelligence: challenges, ethical consideration, and opportunities. J Perinatol. 2023;44(1):44:1–11.
15. Booth RG, Strudwick G, McBride S, O'Connor S. Solano López AL. How the nursing profession should adapt for a digital future. BMJ. 2021;373.
16. Rony MKK, Kayesh I, Bala S, Das, Akter F, Parvin MR. Artificial intelligence in future nursing care: exploring perspectives of nursing professionals - A descriptive qualitative study. Heliyon. 2024;10:e25718.
17. Javvaji CK, Reddy H, Vagha JD, Taksande A, Kommareddy A, Reddy NS, et al. Immersive innovations: exploring the diverse applications of virtual reality (VR) in healthcare. Cureus. 2024;16(3).
18. McAdams RM, Trinh GK. Using virtual Reality–Based simulation in neonatal resuscitation program training. Neoreviews. 2024;25:e567–77.
19. Umoren RA, Schmölzer GM. Virtual simulations for neonatal education. Semin Perinatol. 2023;47:151826.
20. Soghier L. Improving neonatal patient outcomes using Simulation-based education. J Pediatr. 2024;266.

21. Yang SY, Oh YH. The effects of neonatal resuscitation gamification program using immersive virtual reality: A quasi-experimental study. Nurse Educ Today. 2022;117:105464.
22. Bakhos D, Galvin J, Aoustin JM, Robier M, Kerneis S, Bechet G, et al. Training outcomes for audiology students using virtual reality or traditional training methods. PLoS ONE. 2020;15(12 December):1–12.
23. Barchielli C, Marullo C, Bonciani M, Vainieri M. Nurses and the acceptance of innovations in technology-intensive contexts: the need for tailored management strategies. BMC Health Serv Res. 2021;21:639.
24. Breitkreuz KR, Kardong-Edgren S, Gilbert GE, Anderson P, DeBlieck C, Maske M, et al. Nursing faculty perceptions of a virtual reality catheter insertion game: A multisite international study. Clin Simul Nurs. 2021;53:49–58.
25. Saab MM, Landers M, Murphy D, O'Mahony B, Cooke E, O'Driscoll M, et al. Nursing students' views of using virtual reality in healthcare: A qualitative study. J Clin Nurs. 2022;31:1228–42.
26. Sung H, Kim M, Park J, Shin N, Han Y. Effectiveness of Virtual Reality in Healthcare Education: Systematic Review and Meta-Analysis. Sustainability 2024, Vol 16, Page 8520. 2024;16:8520.
27. Timans R, Wouters P, Heilbron J. Mixed methods research: what it is and what it could be. Theory Soc. 2019;48:193–216.
28. Cho MK, Kim MY. Enhancing nursing competency through virtual reality simulation among nursing students: a systematic review and meta-analysis. Front Med (Lausanne). 2024;11:1351300.
29. Dudley J, Yin L, Garaj V, Kristensson PO. Inclusive immersion: a review of efforts to improve accessibility in virtual reality, augmented reality and the metaverse. Virtual Real 2023. 2023;27(4):27:2989–3020.
30. Creed C, Al-Kalbani M, Theil A, Sarcar S, Williams I. Inclusive AR/VR: accessibility barriers for immersive technologies. Univers Access Inf Soc. 2024;23:59–73.
31. Kolb AY, Kolb DA. Experiential learning theory. Encyclopedia Sci Learn. 2012;:1215–9.
32. Kolb DA. Experiential learning: Experience as the source of learning and development, Kolb DA, Prentice-Hall International, Hempstead H. Herts., 1984. No. of pages: xiii + 256. J Organ Behav. 1984;8:359–60.
33. Wijnen-Meijer M, Brandhuber T, Schneider A, Berberat PO. Implementing Kolb´s experiential learning cycle by linking real experience, Case-Based discussion and simulation. J Med Educ Curric Dev. 2022;9:23821205221091510.
34. Sawyer T, McBride ME, Ades A, Kapadia VS, Leone TA, Lakshminrusimha S et al. Considerations on the use of neonatal and pediatric resuscitation guidelines for hospitalized neonates and infants: on behalf of the American heart association emergency cardiovascular care committee and the American academy of pediatrics. Pediatrics. 2024;153.
35. Kolcun K, Zellefrow C, Karl J, Ulloa J, Zehala A, Zeno R, et al. Identifying best practices for virtual nursing clinical education: A scoping review. J Prof Nurs. 2023;48:128–46.
36. Weeks KW, Coben D, O'Neill D, Jones A, Weeks A, Brown M, et al. Developing and integrating nursing competence through authentic technology-enhanced clinical simulation education: pedagogies for reconceptualising the theory-practice gap. Nurse Educ Pract. 2019;37:29–38.
37. Foronda CL, Fernandez-Burgos M, Nadeau C, Kelley CN, Henry MN. Virtual simulation in nursing education: A systematic review spanning 1996 to 2018. Simul Healthc. 2020;15:46–54.
38. Liu Y, Li R, Diao Y, Hou M, Yuan H, Zhang X. An analysis of factors influencing undergraduate students' learning preference in nursing laboratory courses with virtual reality technology: A scoping review. Educ Inf Technol (Dordr). 2024. https://doi.org/10.1007/S10639-024-13149-1.
39. Weston J, Zauche LH. Comparison of virtual simulation to clinical practice for prelicensure nursing students in pediatrics. Nurse Educ. 2021;46:E95–8.
40. Hardenberg J, Rana I, Tori K. Simulation exposure improves clinical skills for postgraduate critical care nurses. Clin Simul Nurs. 2019;28:39–45.
41. Keys E, Luctkar-Flude M, Tyerman J, Sears K, Woo K. The integration of virtual simulation gaming into undergraduate nursing resuscitation education: a pilot randomised controlled trial. Clin Simul Nurs. 2021;54:54–61.
42. Demirtas A, Guvenc G, Aslan Ö, Unver V, Basak T, Kaya C. Effectiveness of simulation-based cardiopulmonary resuscitation training programs on fourth-year nursing students. Australasian Emerg Care. 2021;24:4–10.
43. Chernikova O, Heitzmann N, Stadler M, Holzberger D, Seidel T, Fischer F. Simulation-based learning in higher education: a meta-analysis. Rev Educ Res. 2020;90:499–541.
44. Massoth C, Röder H, Ohlenburg H, Hessler M, Zarbock A, Pöpping DM, et al. High-fidelity is not superior to low-fidelity simulation but leads to overconfidence in medical students. BMC Med Educ. 2019;19:1–8.
45. Li Y, Lv Y, Dorol RD, Wu J, Ma A, Liu Q, et al. Integrative virtual nursing simulation in teaching cardiopulmonary resuscitation: A blended learning approach. Australas Emerg Care. 2024;27:37–41.
46. Svellingen AH, Forstrønen A, Assmus J, Røykenes K, Brattebø G. Simulation-based education and the effect of multiple simulation sessions- randomised controlled study. Nurse Educ Today. 2021;106.
47. Labrague LJ, McEnroe-Petitte DM, Bowling AM, Nwafor CE, Tsaras K. High-fidelity simulation and nursing students' anxiety and self-confidence: A systematic review. Nurs Forum. 2019;54:358–68.
48. Farsi Z, Yazdani M, Butler S, Nezamzadeh M, Mirlashari J. Comparative effectiveness of simulation versus serious game for training nursing students in cardiopulmonary resuscitation: a randomized control trial. Int J Comput Games Technol. 2021;2021:6695077.
49. Alharbi A, Nurfianti A, Mullen RF, McClure JD, Miller WH. The effectiveness of simulation-based learning (SBL) on students' knowledge and skills in nursing programs: a systematic review. BMC Med Educ. 2024;24:1099.
50. Goldsworthy S, Patterson JD, Dobbs M, Afzal A, Deboer S. How does simulation impact Building competency and confidence in recognition and response to the adult and paediatric deteriorating patient among undergraduate nursing students? Clin Simul Nurs. 2019;28:25–32.
51. Ka Ling F, Lim Binti Abdullah K, Seng Chiew G, Danaee M, Chan CMH. The impact of high fidelity patient simulation on the level of knowledge and critical thinking skills in code blue management among undergraduate nursing students in Malaysia. Sage Open. 2021;11:21582440211007124.
52. Seol J, Lee O. Effects of cardiopulmonary resuscitation training for Mozambican nursing students in a low-resource setting: an intervention study. Nurse Educ Today. 2020;90:104433.
53. Padilha JM, Machado PP, Ribeiro A, Ramos J, Costa P. Clinical virtual simulation in nursing education: randomized controlled trial. J Med Internet Res. 2019;21:e11529.
54. Sarvan S, Efe E. The effect of neonatal resuscitation training based on a serious game simulation method on nursing students' knowledge, skills, satisfaction and self-confidence levels: a randomized controlled trial. Nurse Educ Today. 2022;111:105298.
55. D'cunha RJ, Fernandes SF, Sherif L. Utility of simulation as a teaching tool for nursing staff involved in code blue management. Indian J Crit Care Med: Peer-reviewed Off Public Indian Soc Crit Care Med. 2021;25:878.
56. Charlier N, Van Der Stock L, Iserbyt P. Comparing student nurse knowledge and performance of basic life support algorithm actions: an observational post-retention test design study. Nurse Educ Pract. 2020;43:102714.
57. Arrogante O, Ríos-Díaz J, Carrión-García L, Samith S, González-Romero GM, Caperos JM. Deliberate practice in resuscitation training using a feedback device, and the effects of the physical characteristics of the rescuer on the acquisition and retention of cardiopulmonary resuscitation skills: randomized clinical trial. Int Emerg Nurs. 2021;58:101037.
58. Bell IH, Pot-Kolder R, Rizzo A, Rus-Calafell M, Cardi V, Cella M, et al. Advances in the use of virtual reality to treat mental health conditions. Nat Reviews Psychol. 2024;2024 3:8.
59. Bryant L, Brunner M, Hemsley B. A review of virtual reality technologies in the field of communication disability: implications for practice and research. Disabil Rehabil Assist Technol. 2020;15:365–72.
60. Lavoie R, Main K, King C, King D. Virtual experience, real consequences: the potential negative emotional consequences of virtual reality gameplay. Virtual Real. 2021;25:69–81.
61. Rahouti A, Lovreglio R, Datoussaïd S, Descamps T. Prototyping and validating a Non-immersive virtual reality serious game for healthcare fire safety training. Fire Technol. 2021;57:3041–78.
62. Hamad A, Jia B. How virtual reality technology has changed our lives: an overview of the current and potential applications and limitations. Int J Environ Res Public Health 2022. 2022;19(11278):19:11278.
63. Alhassan M, Alhamad F, Bokhary K, Almustanyir A. Effects of virtual reality Head-mounted displays on oculomotor functions. Int J Ophthalmol Visual Sci. 2021;6:10.
64. Bruno RR, Wolff G, Wernly B, Masyuk M, Piayda K, Leaver S et al. Virtual and augmented reality in critical care medicine: the patient's, clinician's, and researcher's perspective. Crit Care. 2022;26.
65. Wijnen-Meijer M, Brandhuber T, Schneider A, Berberat PO. Implementing Kolb´s Experiential Learning Cycle by Linking Real Experience, Case-Based Discussion and Simulation. https://doi.org/10.1177/23821205221091511. 2022;9:238212052210915.
66. Pang CG, Cai Y. Transforming Learning Experiences Through Affordances of Virtual and Augmented Reality. 2023;:109–65.

67. Asoodar M, Janesarvatan F, Yu H, de Jong N. Theoretical foundations and implications of augmented reality, virtual reality, and mixed reality for immersive learning in health professions education. Adv Simul. 2024;9:1–19.
68. Momin S, Rustogi D, Soraisham AS. Organization of delivery room resuscitation for High-Risk neonates. Curr Treat Options Pediatr. 2024;10:110–25.
69. Yu M, Yang M, Ku B, Mann JS. Effects of virtual reality simulation program regarding High-risk neonatal infection control on nursing students. Asian Nurs Res (Korean Soc Nurs Sci). 2021;15:189–96.

Publisher's note