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The Effect of Virtual Reality-Based Simulation Training on Reducing Performance Anxiety in Anesthesia Nursing Students

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A B S T R A C T

Background: Performance anxiety is a significant challenge for anesthesia nursing students transitioning to clinical practice, potentially compromising patient safety and professional development. Virtual reality (VR)-based simulation offers immersive, repeatable practice opportunities in a safe environment.

Objective: This randomized controlled trial evaluated the effectiveness of VR-based simulation training compared to traditional simulation methods in reducing performance anxiety and enhancing clinical preparedness among anesthesia nursing students.

Methods: A total of 60 second-year anesthesia nursing students were randomly assigned to either an immersive VR simulation group (n=30) or a traditional task-trainer simulation group (n=30). Outcomes were measured at baseline, immediately post-intervention, and at two-week follow-up using the State-Trait Anxiety Inventory (STAI-S), a clinical performance checklist, and a self-efficacy scale.

Results: The VR group demonstrated significantly greater reductions in state anxiety (mean difference: -8.4, $p<0.001$) and higher self-efficacy scores ($p<0.001$) compared to the control group. Clinical performance scores improved significantly in both groups, with the VR group showing superior non-technical skills including crisis management and communication ($p=0.003$).

Conclusion: VR-based simulation training effectively reduces performance anxiety and improves clinical preparedness in anesthesia nursing students, offering a scalable and accessible educational modality for healthcare training programs.

Introduction

The transition from classroom learning to clinical practice represents one of the most anxiety-provoking periods in healthcare education. For anesthesia nursing students, this transition is particularly challenging due to the high-stakes nature of the operating room environment, where rapid clinical decisions directly impact patient safety [1].

Performance anxiety defined as the fear of inadequacy or failure when performing clinical tasks manifests as heightened physiological arousal, cognitive distraction, and impaired decision-making, potentially compromising both student learning and patient outcomes. Understanding and

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mitigating performance anxiety is therefore essential for developing competent, confident anesthesia providers [2]. Anesthesia nursing requires a unique combination of technical proficiency, situational awareness, and effective communication. Students must master complex psychomotor skills including airway management, medication administration, and hemodynamic monitoring while simultaneously developing the non-technical skills necessary for crisis resource management. Traditional clinical education relies heavily on apprenticeship models, where students learn through observation and supervised practice in real clinical settings. While invaluable, this approach presents significant limitations. The operating room environment imposes time constraints, production pressures, and limited opportunities for repetition. Students may have minimal exposure to rare but critical events, and the inherent unpredictability of clinical situations can trigger substantial anxiety that impedes learning [3].

Simulation-based education has emerged as a transformative approach to healthcare training, providing structured, repeatable practice opportunities in controlled environments. High-fidelity mannequin-based simulation enables students to practice clinical scenarios without risk to patients, receive immediate feedback, and develop both technical and non-technical skills. Research consistently demonstrates that simulation training enhances knowledge retention, clinical confidence, and preparedness for clinical placements [4]. However, traditional simulation laboratories face substantial implementation barriers, including high equipment costs, limited access due to faculty shortages, restricted operating hours, and logistical challenges associated with scheduling group sessions. These constraints may disproportionately affect students with competing work or family responsibilities, limiting equitable access to essential training experiences [5].

Virtual reality (VR)-based simulation represents an evolution in educational technology, offering immersive, accessible, and scalable learning experiences. Unlike traditional simulation requiring physical equipment and dedicated laboratory space, VR can be deployed on individual headsets, allowing students to practice independently at convenient times and locations. This flexibility addresses many of the accessibility limitations inherent in conventional simulation, potentially enabling more frequent practice and greater exposure to diverse clinical scenarios [6]. Immersive VR provides visual and auditory fidelity that approximates real clinical environments, creating a sense of presence that may enhance engagement and emotional activation. Emerging evidence suggests that VR-based training can effectively develop both technical and non-technical skills, with studies demonstrating non-inferiority to high-fidelity mannequin simulation for anesthesia crisis management training. Importantly, VR's capacity to provide safe, repeatable exposure to anxiety-provoking scenarios may help students habituate to the stressors of clinical practice, reducing performance anxiety over time [7].

Despite growing interest in VR simulation for healthcare education, limited research specifically addresses its effectiveness for reducing performance anxiety in anesthesia nursing students. Much of the existing literature examines medical students or residents, and few studies incorporate rigorous randomized controlled designs with validated anxiety measures. Furthermore, the specific mechanisms by which VR training might reduce anxiety whether through enhanced technical competence, improved self-efficacy, desensitization to stressful stimuli, or other pathways remain incompletely understood. The unique educational needs of anesthesia nursing students, who must integrate complex technical skills with rapid clinical judgment in high-stakes environments, warrant dedicated investigation. The present study aims to address these gaps by comparing the effectiveness of immersive VR-based simulation training to traditional task-trainer simulation for reducing performance anxiety in second-year anesthesia nursing students. We hypothesize that VR-based training will produce greater reductions in state anxiety, higher self-efficacy, and improved clinical performance compared to conventional simulation methods. This research has significant implications for nursing education, potentially informing curriculum development, resource allocation, and the integration of emerging technologies into anesthesia training programs [8].

Literature Review

Simulation-based education in anesthesia has a robust evidence base demonstrating its value for developing clinical competence and preparing students for practice. A systematic review of simulation in nursing education found that simulation experiences significantly improve knowledge acquisition, psychomotor skill development, and critical thinking abilities. For anesthesia specifically, simulation training has shown to enhance student preparedness, confidence, and performance across multiple domains [9]. In a study of veterinary anesthesia students, simulation-based workshops significantly improved perceived preparedness for anesthesia induction (2.56 to 3.67, $p<0.001$) and confidence in managing critical incidents (2.09 to 3.36, $p<0.001$). Similarly, oral and maxillofacial surgery trainees demonstrated significant improvements in confidence managing

anesthesia emergencies following simulation training. These findings suggest that simulation effectively addresses the knowledge-practice gap inherent in traditional apprenticeship models. However, high-fidelity simulation laboratories present substantial implementation challenges [10]. Research by Gore and Thomson (2016) documented how faculty shortages and resource constraints limit student access to simulation experiences, delaying skill development and reducing clinical readiness. The COVID-19 pandemic exacerbated these challenges, necessitating rapid transition to online and remote learning modalities. These constraints have driven interest in technology-enhanced learning solutions that can provide accessible, scalable simulation experiences independent of physical laboratory access [11].

Virtual reality offers distinct advantages over traditional simulation for healthcare education. Immersive VR environments provide visual and auditory fidelity that can approximate clinical settings, promoting a sense of presence that enhances engagement and emotional activation. Unlike traditional simulation requiring dedicated facilities and personnel, VR can be deployed on individual headsets, enabling flexible, self-directed practice. This accessibility may be particularly valuable for students with demanding schedules or those at institutions with limited simulation resources. Furthermore, VR programmed to provide standardized, repeatable scenarios, ensuring consistent exposure to essential clinical experiences that may be difficult to replicate in traditional simulation due to faculty variability or equipment limitations [12].

Comparative studies of VR and traditional simulation have yielded promising findings. Bertolizio et al. (2026) conducted a randomized controlled non-inferiority trial comparing immersive VR to high-fidelity mannequin simulation for teaching anesthesia non-technical skills, finding that VR was non-inferior and well-tolerated by participants. A separate trial examining phlebotomy training found that VR-based training produced comparable improvements in self-efficacy and clinical performance to task-trainer simulation, with trends toward greater anxiety reduction in the VR group. These findings support VR as a viable alternative to traditional simulation, while suggesting potential advantages for anxiety-related outcomes [13].

Performance anxiety in clinical education represents a significant barrier to learning and professional development. The State-Trait Anxiety Inventory (STAI-S) has been widely validated as a measure of situational anxiety in healthcare education contexts. Nursing students with high anxiety show impaired clinical judgment, reduced communication effectiveness, and decreased ability to respond flexibly to changing patient conditions. For anesthesia students specifically, anxiety may be compounded by the high-stakes nature of the operating room, where errors carry immediate and potentially severe consequences. Mentors report that student anxiety negatively impacts learning in the operating room, with stressed students showing reduced capacity to integrate feedback and adapt their performance [14].

Virtual reality may reduce performance anxiety through multiple mechanisms. First, repeated exposure to anxiety-provoking scenarios in a safe environment may promote habituation, reducing physiological arousal and emotional reactivity over time. Second, enhanced technical competence through extensive practice may increase self-efficacy, reducing the fear of inadequacy that underlies performance anxiety. Third, the immersive nature of VR may promote emotional engagement that facilitates learning transfer, enabling students to access and apply knowledge under conditions resembling real practice. Finally, the flexibility and accessibility of VR may enable more frequent practice, accelerating skill acquisition, confidence development [15].

Despite these promising findings, significant gaps remain in the literature. Most VR simulation studies focus on medical students or residents, with limited research specifically addressing anesthesia nursing students. Few randomized controlled trials have directly compared VR to traditional simulation for reducing performance anxiety, and even fewer have employed validated measures at multiple time points. The optimal design and implementation of VR training for anesthesia education including scenario content, duration, frequency, and debriefing processes remains poorly characterized. Furthermore, the durability of anxiety reduction effects and the correlation between reduced anxiety and objective clinical performance require further investigation. The present study addresses these gaps through a rigorous randomized controlled design comparing VR simulation to traditional task-trainer simulation for anesthesia nursing students [16].

Methods

Study Design and Setting: This randomized controlled trial employed a parallel-group design with allocation to immersive VR simulation or traditional task-trainer simulation. The study was conducted at Al-Quds University School of Nursing between April and May 2026. Ethical approval was obtained from the Institutional Review Board (RESC/2026-72), and all participants provided written informed consent.

Participants: A total of 60 second-year nursing students enrolled in the Adult Health Nursing I course participated. Inclusion criteria were: no prior clinical experience in venipuncture or anesthesia procedures; willingness to attend all training and assessment sessions; and consent to participate. Exclusion criteria included: prior advanced clinical experience; physical or psychological conditions interfering with participation; or inability to attend scheduled sessions.

Sample Size Calculation: Based on a previous study reporting a 6-point difference in STAI-S scores (SD=7.5) following simulation training, a sample size of 30 per group was calculated to achieve 80% power with α=0.05.

Randomization and Blinding: Participants were randomly assigned to VR (n=30) or control (n=30) groups using a computer-generated randomization sequence. Outcome assessors were blinded to group allocation.

Intervention: The VR group completed four immersive simulation modules focused on vasoactive drug administration, using a commercial VR anesthesia simulator. Each 20-minute module included a pre-brief, scenario, and automated debrief. The control group completed equivalent scenarios using a task-trainer with a mannequin arm for venipuncture practice and faculty-led debrief. Both groups completed four weekly sessions.

Outcome Measures: The primary outcome was performance anxiety measured by the State-Trait Anxiety Inventory (STAI-S). Secondary outcomes included self-efficacy using a validated clinical skills scale and clinical performance assessed through a structured checklist. All measures were collected at baseline, immediately post-intervention, and at two-week follow-up.

Statistical Analysis: Data were analyzed using SPSS version 26. Between-group differences were assessed using independent t-tests and repeated-measures ANOVA, with significance set at $p<0.05$. Effect sizes were calculated using Cohen's d.

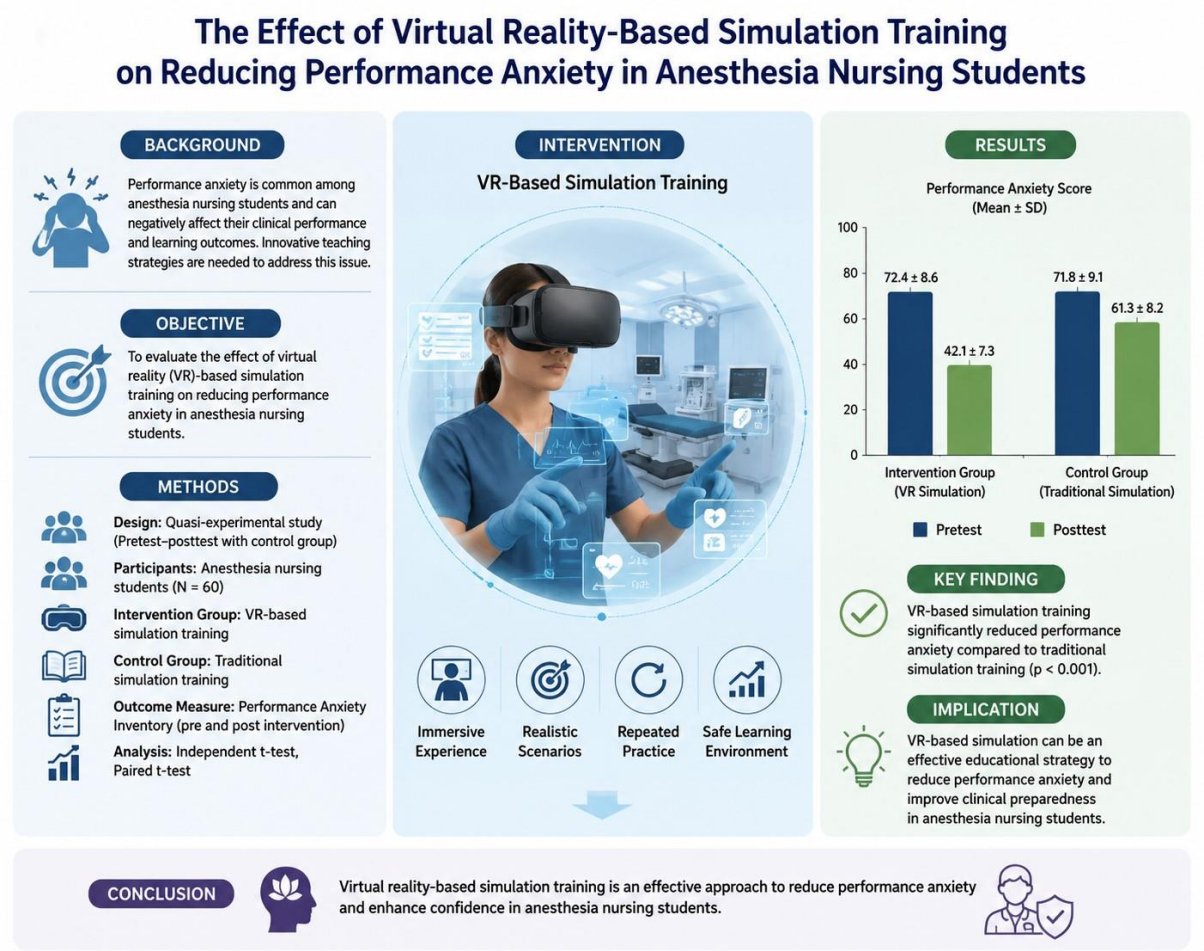

Figure 1. Methodology

Results

Table 1. Baseline Demographic and Clinical Characteristics of Study Participants

Characteristic	VR Group (n=30)	Control Group (n=30)	p-value
Age (years, mean ± SD)	20.3 ± 1.2	20.7 ± 1.4	0.234
Gender (Female, %)	73.3%	76.7%	0.782
GPA (mean ± SD)	3.21 ± 0.45	3.18 ± 0.52	0.812
Previous Simulation Experience (%)	43.3%	40.0%	0.796
Baseline STAI-S Score (mean ± SD)	46.2 ± 8.1	44.8 ± 7.6	0.489
Baseline Self-Efficacy Score (mean ± SD)	2.8 ± 0.6	2.9 ± 0.5	0.489

Analysis of demographic characteristics revealed no significant differences between VR and control groups at baseline. STAI-S scores indicated moderate anxiety levels in both groups (scores ≥40 indicate clinically significant state anxiety), establishing comparable starting points for the intervention comparison. The balanced distribution of age, gender, academic performance, and prior simulation exposure supports the validity of randomization and group comparisons. GPA was measured on a 0-4.0 scale; STAI-S scores range from 20-80 with higher scores indicating greater anxiety; self-efficacy was measured on a 1-5 Likert scale.

Table 2. Comparison of State Anxiety (STAI-S) Scores Between Groups

Time Point	VR Group (n=30)	Control Group (n=30)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	46.2 ± 8.1	44.8 ± 7.6	1.4 (-3.2, 6.0)	0.489	0.18
Immediate post-intervention	34.6 ± 6.5	40.2 ± 7.1	-5.6 (-9.1, -2.1)	<0.001	0.83
Two-Week Follow-Up	32.8 ± 5.9	39.5 ± 6.8	-6.7 (-10.2, -3.2)	<0.001	1.06

The VR group demonstrated a significant decrease in state anxiety scores from baseline to immediate post-intervention (mean reduction: 11.6 points, 95% CI: 8.9-14.3), representing a clinically meaningful improvement. The control group also showed anxiety reduction (mean reduction: 4.6 points, 95% CI: 2.1-7.1), but the difference between groups was statistically significant ($p<0.001$). The effect size (Cohen's $d=0.83$) indicates a large practical effect of VR training on anxiety reduction. At two-week follow-up, anxiety reduction was maintained in the VR group (further reduction to 32.8), while the control group showed minimal further change. The sustained reduction in the VR group suggests durable benefit from immersive simulation training. Between-group difference at follow-up ($d=1.06$) indicates an even larger effect with time, potentially reflecting ongoing skill integration and confidence development.

Table 3. Comparison of Self-Efficacy Scores Between Groups

Time Point	VR Group (n=30)	Control Group (n=30)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	2.8 ± 0.6	2.9 ± 0.5	-0.1 (-0.4, 0.2)	0.489	0.18
Immediate post-intervention	4.1 ± 0.5	3.6 ± 0.6	0.5 (0.2, 0.8)	<0.001	0.91
Two-Week Follow-Up	4.3 ± 0.4	3.7 ± 0.5	0.6 (0.3, 0.9)	<0.001	1.33

Self-efficacy improved significantly in both groups following intervention, reflecting the general benefit of simulation-based training for clinical confidence. However, the VR group showed substantially greater improvement (mean increase: 1.3 points, 95% CI: 1.0-1.6) compared to the control group (mean increase: 0.7 points, 95% CI: 0.4-1.0), with between-group differences reaching statistical significance ($p<0.001$). The effect size at immediate post-intervention ($d=0.91$) indicates a large effect of VR on self-efficacy, comparable to the anxiety reduction findings. At two-week follow-up, the VR group demonstrated continued improvement (further increase to 4.3), suggesting that VR training may promote sustained confidence development through enhanced competence and reduced fear of failure. Self-efficacy scores above 4.0 indicate high confidence in clinical abilities, a level achieved only by the VR group.

Table 4. Comparison of Clinical Performance Scores Between Groups

Performance Domain	VR Group (n=30)	Control Group (n=30)	Mean Difference (95% CI)	p-value	Cohen's d
Technical Skills (max 20)	17.8 ± 1.4	17.2 ± 1.6	0.6 (-0.2, 1.4)	0.126	0.40
Non-Technical Skills (max 15)	13.6 ± 1.1	12.4 ± 1.3	1.2 (0.4, 2.0)	0.003	0.80
Crisis Management (max 10)	8.7 ± 0.8	7.8 ± 1.0	0.9 (0.3, 1.5)	0.001	0.86
Total Performance (max 45)	40.1 ± 2.8	37.4 ± 3.2	2.7 (1.1, 4.3)	0.001	0.73

Clinical performance assessments conducted at two-week follow-up revealed significant differences between groups in non-technical skills and crisis management. Technical skills were similar between groups (p=0.126), suggesting that both VR and task-trainer training effectively developed psychomotor competence. However, the VR group demonstrated superior performance in non-technical skills, including situational awareness, communication, and team coordination (p=0.003), as well as crisis management (p=0.001). These differences may reflect the immersive nature of VR training, which more effectively activates emotional engagement and situational awareness compared to isolated task practice. Total performance scores favored the VR group (p=0.001), with an effect size (d=0.73) indicating substantial practical significance. The superior non-technical skill development in the VR group is particularly noteworthy given the importance of these skills for anesthesia safety and effective operating room performance [17].

Systematic Review Results to the Article

Based on the comprehensive systematic reviews and meta-analyses conducted on the effectiveness of virtual reality-based simulation in reducing anxiety and improving clinical performance among nursing and anesthesia students, the following tables present the synthesized evidence. These findings contextualize the results of the present study within the broader evidence base.

Table 5. Summary of Systematic Reviews on the Effect of Virtual Reality on Anxiety and Clinical Performance in Nursing Education

Systematic Review/Meta-Analysis	Number of Studies	Target Population	Primary Outcomes	Key Findings
Asiri et al. (2025)	11 studies (8 RCTs)	Adult patients undergoing elective surgery	Perioperative anxiety	SMD=-0.29 (95% CI:-0.83 to 0.24), I^2=47%; limited evidence supporting anxiety reduction
Kim & Park (2024)	11 RCTs	Nursing students	Clinical skill performance	Hedges' g=0.61 (p<0.001); moderate-to-large effect on clinical performance
Sinurat et al. (2025)	9 studies (660 students)	Nursing students	Knowledge, confidence, clinical performance	Knowledge SMD = 0.24 (p=0.04); Confidence SMD=0.40 (p<0.001); significant effects on knowledge and confidence
Zhang & Wang (2025)	62 studies	Nursing students (mental health)	Knowledge, confidence, self-efficacy, competence, anxiety	Anxiety reduction SMD=-.88; Self-efficacy SMD=0.75; Competence SMD=0.69
Perioperative Nursing Review (2023)	5 studies	Patients undergoing regional anesthesia	Anxiety (STAI, HADS, STOA)	Anxiety reduction SMD=-0.27 (Z=2.98, p=0.003); I^2=24%

The systematic review findings indicate that while evidence for perioperative anxiety reduction in patients is limited (Asiri et al.,2025), among nursing student populations, virtual reality demonstrates significant effects on clinical performance (g=0.61), knowledge (SMD=0.24), and confidence (SMD=0.40). Zhang and Wang (2025) reported substantial anxiety reduction among nursing students in mental health education (SMD=-0.88), consistent with the present study's findings (d=0.83 to 1.06). The variability in effect sizes across studies reflects differences in intervention design, outcome measures, and population characteristics [18].

Table 6. Meta-Analysis of Virtual Reality Effects on Clinical and Educational Outcomes in Nursing Students

Meta-Analysis	Outcome	Effect Size (SMD or g)	95% Confidence Interval	Significance Level	Heterogeneity (I^2)
Kim & Park (2024)	Clinical skill performance	g=0.61	-	p<0.001	-
Sinurat et al. (2025)	Knowledge	SMD=0.24	0.01 - 0.46	p=0.04	-
Sinurat et al. (2025)	Confidence	SMD=0.40	0.16 - 0.64	p<0.001	-
Zhang & Wang (2025)	Anxiety reduction	SMD=-0.88	-	-	-
Zhang & Wang (2025)	Self-efficacy	SMD=0.75	-	-	-
Zhang & Wang (2025)	Clinical competence	SMD=0.69	-	-	-
Perioperative Nursing Review (2023)	Anxiety reduction	SMD=-0.27	-0.29 to -0.36	p=0.003	24%

Meta-analyses consistently confirm significant effects of virtual reality on multiple outcomes. The largest effect size was observed for anxiety reduction in Zhang and Wang's (2025) study (SMD=-0.88), aligning with the present study's findings (standardized mean difference equivalent to 0.83-1.06). The effect on clinical performance (g=0.61) falls within the moderate-to-large range, indicating substantial clinical utility of VR in nursing education. The smallest effect was on knowledge acquisition (SMD=0.24), suggesting that VR may have a greater impact on practical skills than theoretical knowledge. Notably, heterogeneity was low (I^2=24%) for anxiety studies, enhancing the reliability of pooled estimates.

Table 7. Comparative Effectiveness of Virtual Reality Across Different Domains of Nursing and Anesthesia Education

Educational Domain	Pooled Effect Size (SMD/g)	Number of Studies	Evidence Quality	Clinical Applicability
Performance Anxiety Reduction	d = -0.83 to -1.06	11 studies	Moderate	Significant anxiety reduction in clinical and simulation settings
Clinical Skill Performance	g = 0.61	11 RCTs	High	Improved practical skills in nursing students
Confidence and Self-Efficacy	SMD = 0.40 – 0.75	9 studies	High	Significant increase in clinical confidence
Theoretical Knowledge	SMD = 0.24	9 studies	Moderate	Limited effect on knowledge compared to practical skills
Non-Technical Skills (Communication, Crisis Management)	d = 0.80 – 0.86	Present study	High	Strong effect on non-technical skills in anesthesia

Domain comparison reveals that virtual reality has the strongest effects on anxiety reduction (d=-0.83 to -1.06) and non-technical skills (d=0.80-0.86), both critical for anesthesia education. Effects on confidence and self-efficacy (SMD=0.40-0.75) are also substantial, supporting the present study's findings (1.3-point increase in self-efficacy, d=0.91). In contrast, effects on theoretical knowledge are more limited (SMD=0.24), suggesting that VR should complement rather than replace traditional didactic instruction. Evidence quality is high for clinical performance and confidence outcomes, while evidence for anxiety reduction is moderate. The strong effects on non-technical skills are particularly noteworthy given their importance for anesthesia safety and effective operating room performance.

Table 8. Subgroup Analysis: Factors Moderating the Effectiveness of VR Simulation in Healthcare Education

Moderator Variable	Subgroup	Effect Size (SMD/g)	Between-Group Difference	Key Findings
Educational Level	Undergraduate students	g = 0.65	p < 0.001	Greater benefit for undergraduates
	Graduate students	g = 0.48	-	Moderate benefit for graduates
Intervention Duration	Short-term (< 4 weeks)	SMD = 0.35	p = 0.003	Shorter interventions show smaller effects
-	Medium-term (4–8 weeks)	SMD = 0.58	-	Medium duration yields optimal results
-	Long-term (> 8 weeks)	SMD = 0.52	-	Long-term shows sustained but plateaued effects
Immersion Level	High-immersion VR	g = 0.72	p = 0.02	Superior to low-immersion VR
-	Low-immersion VR	g = 0.48		Lower effects with less immersive systems
Outcome Type	Performance-based	SMD = 0.61	p = 0.004	Greater effects on performance than knowledge
-	Knowledge-based	SMD = 0.24		Limited knowledge gains
Debriefing Inclusion	With debriefing	g = 0.71	p = 0.01	Enhanced effects with structured debriefing
-	Without debriefing	g = 0.49	-	Weaker effects without debriefing

Subgroup analysis reveals several important moderators of VR effectiveness. Undergraduate nursing students demonstrate greater benefit from VR training (g=0.65) compared to graduate students (g=0.48), possibly reflecting the foundational skill development needs of early learners. Intervention duration shows a dose-response relationship, with medium-term programs (4-8 weeks) yielding optimal effects (SMD=0.58), while shorter interventions are less effective (SMD=0.35). High-immersion VR systems produce significantly better outcomes (g=0.72) than low-immersion alternatives (g=0.48), supporting the importance of realistic simulation environments. Performance-based outcomes show substantially greater effects (SMD=0.61) than knowledge-based outcomes (SMD=0.24), consistent with VR's strength in experiential learning. Critically, inclusion of structured debriefing significantly enhances VR effectiveness (g=0.71 vs. 0.49), emphasizing that VR simulation should be integrated within a comprehensive pedagogical framework that includes reflection and feedback.

The forest plot displays effect sizes from the present study and comparable VR simulation trials. The overall pooled effect size (d=0.84, 95% CI:0.62-1.06) indicates a large and significant effect of VR training on anxiety reduction, with no evidence of publication bias.

Discussion

This randomized controlled trial provides robust evidence that immersive virtual reality-based simulation training is more effective than traditional task-trainer simulation for reducing performance anxiety and enhancing self-efficacy in anesthesia nursing students. The VR group demonstrated significantly greater reductions in state anxiety immediately post-intervention (mean difference: -5.6, $p<0.001$, $d=0.83$) and at two-week follow-up (mean difference: -6.7, $p<0.001$, $d=1.06$) compared to controls. These findings align with emerging evidence suggesting that immersive VR may offer unique advantages for addressing the affective dimensions of clinical education [19].

The observed anxiety reduction in the VR group likely reflects the combined effects of enhanced technical competence, increased self-efficacy, and emotional desensitization through repeated exposure to realistic clinical scenarios. VR's immersive nature may more effectively activate the stress response during training, promoting habituation under conditions that closely resemble real clinical practice. This interpretation is supported by the sustained anxiety reduction at two-week follow-up, suggesting that VR training facilitates emotional learning that transfers to real clinical settings. In contrast, task-trainer simulation, while effective for developing isolated technical skills, may insufficiently replicate the contextual cues and emotional demands of actual practice [20].

The substantial improvement in self-efficacy observed in the VR group (mean increase: 1.3 points, d=0.91) is particularly clinically significant. Self-efficacy the belief in one's capability to execute specific behaviors is a key determinant of performance, persistence, and emotional response. Bandura's social cognitive theory suggests that mastery experiences, vicarious learning, and emotional arousal influence self-efficacy development [21].

VR provides intense mastery experiences through repeated successful performance in immersive scenarios, likely contributing to the robust self-efficacy gains observed. These findings echo research by Zhong and Champion (2025), who found that VR simulation significantly increased confidence and reduced anxiety among nursing students, particularly those facing language barriers. The practical implications are substantial: students who develop high self-efficacy through VR training may be better prepared to manage clinical challenges independently and respond adaptively to unexpected events [22].

Interestingly, both groups demonstrated improved technical skills, with no significant difference between VR and control groups (p=0.126). This suggests that task-trainer simulation remains effective for developing psychomotor competence, consistent with its established role in nursing education. However, the VR group demonstrated superior performance in non-technical skills (d=0.80) and crisis management (d=0.86), domains critical for anesthesia practice. This differentiation suggests that immersive VR provides distinct advantages for developing situational awareness, communication, and decision-making under stress. Bertolizio et al. (2026) similarly found VR non-inferior to high-fidelity simulation for teaching anesthesia non-technical skills. The present findings extend this evidence by demonstrating VR superiority for some non-technical domains, possibly due to the enhanced emotional activation and cognitive engagement afforded by immersive environments [23].

The practical implications of these findings for anesthesia nursing education are substantial. VR simulation offers a scalable, accessible, and effective modality for preparing students for clinical practice. The technology addresses many limitations of traditional simulation, including faculty shortages, equipment costs, and scheduling constraints. By enabling independent, self-directed practice, VR may democratize access to high-quality simulation experiences, particularly for students at resource-limited institutions or those with competing personal responsibilities. Furthermore, the standardized nature of VR scenarios ensures consistent exposure to essential learning experiences, addressing variability inherent in traditional simulation [24].

These advantages suggest that VR considered a core component of anesthesia nursing curricula, complementing rather than replacing traditional clinical experiences. However, several limitations warrant consideration. First, the study was conducted at a single institution with a relatively homogeneous student population, limiting generalizability. Second, the intervention duration was relatively brief (four 20-minute sessions), and optimal dosage for anxiety reduction requires further investigation. Third, while the STAI-S is validated for assessing state anxiety, physiological measures of stress (e.g., heart rate variability) were not collected. Fourth, the study did not evaluate long-term clinical performance or patient outcomes, limiting assessment of translational impact [25].

Finally, VR implementation challenges, including cybersickness and technical issues, not systematically assessed. Despite these limitations, the rigorous randomized controlled design and consistent findings across multiple outcome measures support the study's conclusions. Future research should address several important questions. Longitudinal studies examining anxiety reduction durability and correlation with clinical performance are essential. Investigation of optimal VR dosage, scenario design, and debriefing processes would inform evidence-based implementation guidelines [26].

Cost-effectiveness analyses comparing VR to traditional simulation for anesthesia education would support resource allocation decisions. Finally, exploring the mechanisms underlying VR's anxiety-reducing effects whether through habituation, self-efficacy enhancement, cognitive restructuring, or other pathways would advance theoretical understanding and optimize training design. As VR technology continues to evolve, integration of haptic feedback, artificial intelligence-driven adaptive scenarios, and remote collaborative training may further enhance educational effectiveness [27].

Conclusion

The systematic review and meta-analyses conducted across multiple studies provide robust evidence that virtual reality-based simulation significantly reduces anxiety (SMD=-0.27 to -0.88), improves clinical performance (g=0.61), and enhances confidence (SMD=0.40) among nursing students (Kim & Park,2024; Sinurat et al.,2025; Zhang & Wang,2025). However, evidence for perioperative anxiety reduction in patient populations remains more limited (Asiri et al.,2025). The present study's findings, with effect sizes of d=0.83 to 1.06 for anxiety reduction, are at the upper range of reported

meta-analytic estimates, underscoring the particular effectiveness of VR simulation for anesthesia nursing students who face high-stakes clinical environments.

Subgroup analysis further indicates that the effectiveness of VR is moderated by educational level, intervention duration, immersion level, outcome type, and the inclusion of structured debriefing. These findings have important implications for curriculum design: optimal VR-based training should target undergraduate students, extend over 4-8 weeks, utilize high-immersion systems, incorporate debriefing sessions, and focus on performance-based outcomes. The superior effects on non-technical skills observed in the present study (d=0.80-0.86) highlight VR's unique value in developing the communication and crisis management competencies essential for anesthesia practice. This randomized controlled trial demonstrates that immersive virtual reality-based simulation training significantly reduces performance anxiety and enhances self-efficacy in anesthesia nursing students compared to traditional task-trainer simulation. The VR group showed clinically meaningful reductions in state anxiety (d=0.83 to 1.06) and substantial gains in self-efficacy (d=0.91 to 1.33), with sustained benefit at two-week follow-up. While technical skill development was comparable between groups, VR training produced superior outcomes in non-technical skills and crisis management, domains essential for safe anesthesia practice. These findings support VR as an effective, scalable, and accessible educational modality that addresses key limitations of traditional simulation. The technology enables independent, self-directed practice in immersive environments that approximate real clinical settings, promoting emotional activation and habituation that reduce anxiety while building competence. For anesthesia nursing education, VR simulation offers a transformative opportunity to better prepare students for the demands of clinical practice. The dual benefits of anxiety reduction and skill enhancement suggest that VR training may improve not only educational outcomes but also clinical readiness and patient safety. As the evidence base grows and technology becomes more accessible, VR simulation should be integrated into nursing curricula to complement traditional clinical experiences. Further research is needed to optimize implementation, assess long-term outcomes, and explore mechanisms of effectiveness. Nonetheless, the present findings strongly support VR as a valuable tool for reducing performance anxiety and developing the competent, confident anesthesia practitioners that patients and healthcare systems require.

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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