

Flipped classroom combined with problem-based learning in peri-operative anaphylaxis training for nurse anesthetists: a randomized controlled trial

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Abstract

Background

Peri-operative anaphylaxis is a rare but life-threatening emergency that demands strong team coordination and rapid response from nurse anesthetists. Although flipped classroom (FC) and problem-based learning (PBL) have shown promise in medical education, their combined effectiveness in the training of nurse anesthetists remains unclear. This study aims to assess the influence of FC-PBL teaching method in the perioperative allergy treatment training on the performance and satisfaction of anesthesia nurses.

Methods

This double blind, randomized controlled trial was conducted at the First Affiliated Hospital of Zhengzhou University between December 15, 2025 and March 31, 2026. A total of 96 nurse anesthetists were randomly assigned to a control group (traditional lectures, $n = 48$) or an experimental group (integrated FC-PBL, $n = 48$). Outcomes included the Team Emergency Assessment Measure (TEAM) score, theoretical knowledge, practical skills, student satisfaction and self-confidence in learning. Independent samples t tests or Mann–Whitney U tests were used for between group comparisons, and paired t tests or Wilcoxon signed rank tests for within group comparisons.

Results

A total of 92 participants completed the study (control group, $n = 45$; experimental group, $n = 47$). After the training, the TEAM total score was significantly higher in the experimental group than in the control group (median 39, 34.5–40 vs. median 37, 35–38; $Z = -2.999$, $P = 0.003$). Significant improvements in favor of the experimental group were observed in the leadership ($P = 0.013$) and teamwork ($P = 0.017$) subscales, whereas task management did not differ significantly between groups ($P = 0.565$). Theoretical knowledge scores were higher in the experimental group (85.40 ± 2.98 vs. 81.80 ± 4.29 ; mean difference 3.60, 95% CI -2.07 to -5.14; $P < 0.001$), as were practical skill scores (41.28 ± 5.34 vs. 39.31 ± 3.78 ; mean difference 1.97, 95% CI 0.06–3.88; $P = 0.044$). The experimental group also reported a significantly higher total score on the satisfaction and self-confidence scale (54.64 ± 4.47 vs. 52.67 ± 4.76 ; $P = 0.044$) and higher self-confidence in learning (33.43 ± 2.51 vs. 32.11 ± 2.53 ; $P = 0.014$), whereas the student satisfaction subscale did not differ significantly between groups (21.21 ± 2.23 vs. 20.56 ± 2.33 ; $P = 0.170$).

Conclusion

The integrated FC-PBL teaching model significantly improved team emergency performance, theoretical knowledge, practical skills, and self-confidence in learning among nurse anesthetists in peri-operative anaphylaxis training, representing an effective and acceptable strategy for continuing education in anesthesia nursing.

Trial Registration

ChiCTR2500114190 (<http://www.chictr.org.cn>). Registered on December 9, 2025.

Introduction

Perioperative anaphylaxis, although relatively rare with a low incidence of 0.4-1 per 10,000, carries a mortality rate as high as 4.8% [1–3]. As first responders in such crises, nurse anesthetists must rapidly identify and manage these events to ensure patient safety and improve outcomes. In 2021, the International Council of Nurses (ICN) officially included nurse anesthetists within the scope of advanced practice nursing through its revised international guidelines [4]. Their role has expanded across the entire perioperative period, requiring a robust command of emergency rescue and advanced life support [5, 6]. However, a significant challenge in training nurse anesthetists lies in the limitations of traditional didactic teaching, which often fails to adequately cultivate essential competencies like critical thinking and teamwork [7–9].

Innovative pedagogical methods are thus needed. The flipped classroom (FC) model shifts knowledge acquisition to the pre-class stage, freeing up class time for skill practice [10–12]. Problem based learning (PBL) triggers students' critical thinking by using real clinical problem situations to promote learning [13–16]. The integration of FC and PBL demonstrates significant potential for enhancing the quality of medical education, particularly in complex clinical areas [17, 18]. This combined model fosters a more active, student-centered learning environment. It promotes deeper cognitive engagement by requiring learners to independently acquire foundational knowledge and then apply, analyze, and synthesize this information collaboratively to solve clinical problems. This synergy has been shown to enhance knowledge retention, critical thinking, self-directed learning capabilities, and the translation of theoretical knowledge into clinical reasoning.

Evidence supporting the efficacy of this combined approach is emerging across medical disciplines. In ophthalmic skill training, theoretical test scores have been significantly improved, and clinical skill performance among students without prior clinical experience has been particularly enhanced by the FC-PBL method [19]. Similarly, in a pediatric nursing course, a qualitative study has revealed that nursing students perceived the combined FC-PBL model as highly beneficial [18]. It stimulated learning interest, enhanced autonomous learning and problem-solving skills, cultivated teamwork, and improved the integration of knowledge with clinical practice. However, it remains unclear whether the FC-PBL model can effectively improve the team emergency performance of nurse anesthetists in peri-operative anaphylaxis.

This study therefore aims to evaluate the impact of FC-PBL training compared to traditional lecture-based education on team performance, knowledge, and clinical skills among nurse anesthetists. We enrolled nurse anesthetists and assessed their teamwork using the TEAM scale, along with theoretical and practical skill scores before and after the training. Student satisfaction and self-confidence in learning were also surveyed across key educational domains. The findings are intended to inform optimal training strategies for peri-operative emergency preparedness.

Methods

Participants and study design

This was a double-blind randomized controlled trial conducted at the First Affiliated Hospital of Zhengzhou University between December 15, 2025 and March 31, 2026. The study was approved by the Research Ethics Committee of the First Affiliated Hospital of Zhengzhou University (2025-KY-1700-001) and was registered at the Chinese Clinical Trial Registry (No. ChiCTR2500114190, registration date: December 9, 2025). This study protocol was performed according to CONSORT guidelines [20]. Written informed consent was obtained from all participants before the training began.

Eligible participants were full-time college degree or above, more than one year of working experience, no previous professional training in perioperative allergic reaction management, cooperate with the training and assessment work throughout the process, and obtain a written informed consent. Exclusion criteria: teaching interruption caused by multiple factors, refusal to participate in this study.

A randomization list was generated by SPSS 26.0 software package (IBM SPSS, Chicago, Illinois, USA) with a randomization ratio of 1:1. Allocation was concealed in sealed envelopes, outcome assessors were blinded to group assignment. Outcome assessors were blinded to group assignment throughout the study.

Intervention

The textbooks, teaching content, lecturers, and total hours of teaching were the same in both groups. Both groups received a 3-hour training program. The control group underwent traditional lecture-based teaching, where instructors delivered systematic theoretical knowledge on perioperative anaphylaxis—including identification, rescue procedures, and teamwork—through multimedia-aided lectures and case discussions, followed by clinical practice.

The experimental group received a combined flipped-classroom and problem-based learning (FC-PBL) approach, as shown in Fig. 1. The pre-class phase was conducted three days before the session. Participants received a package of learning resources. The package included 10-minute micro-video lectures and electronic textbooks as well as clinical case materials on peri-operative anaphylaxis. They were required to complete self-study tasks and an online pre-class test. They also prepared questions

based on assigned clinical problems. Teachers designed the clinical cases and produced the micro-videos. They also offered online support to address learners' questions before class. The in-class phase lasted 180 minutes. Participants were divided into 4 groups with assigned roles. The session began with case introduction and grouping for 15 minutes. Group discussion and analysis of problems and decision-making followed for 45 minutes. Participants then engaged in skill training and simulation exercises for 60 minutes. They used anesthesia equipment and virtual role systems to practice airway management and hemodynamic monitoring as well as team coordination. Each group subsequently presented their case analysis and simulation experience. The instructor then provided feedback and supplemented relevant knowledge for 45 minutes. The session concluded with a summary and question-and-answer period for 15 minutes. The post-class phase was completed within one week. Participants completed knowledge application assignments and reviewed their simulation recordings through the VR system. They took a test and submitted a reflection. They could also schedule individualized training. Teachers evaluated the assignments and provided feedback. They analyzed test results and offered personalized guidance as needed [21].

Outcomes

The primary outcome was the post-training Team Emergency Assessment Measure (TEAM) score [22, 23]. The TEAM scale includes 11 items across three domains: leadership (2 items), teamwork (7 items), and task management (2 items). Each item was rated on a 5-point Likert scale from 0 (never/hardly ever) to 4 (always/nearly always), giving a total score ranging from 0 to 44 [24]. Higher scores indicate better team performance. Raters received standardized TEAM training before assessment [25].

Secondary outcomes consisted of theoretical knowledge scores, practical skill scores, and teaching satisfaction. The theoretical assessment consists of 50 multiple-choice questions (total score: 100 points), and skill assessment consists of 10 operational criteria (total score: 50 points). Both were assessed before and two weeks after training. Two senior anesthesiologists with extensive perioperative emergency experience served as raters, who were blinded to group assignment. The two raters scored independently, and the mean of their ratings was used for subsequent analysis. Student satisfaction and self-confidence in learning were assessed using the Student Satisfaction and Self-Confidence in Learning Scale developed by the National League for Nursing (NLN) [26]. This instrument consists of 13 items rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The scale is divided into two subscales: the Student Satisfaction subscale (5 items) and the Self-Confidence in Learning subscale (8 items).

Sample size

The sample size was estimated based on a pilot study of 10 participants per group. In the pilot data, the median [interquartile range (IQR)] post-training TEAM total score was 37.5 (35–38) in the control group and 39 (37–40) in the experimental group. With a two-sided α of 0.05 and 90% power, the minimum

required number of participants per group was 42 after applying the Pitman efficiency correction for the Mann–Whitney U test. Anticipating a 10% attrition rate, we planned to recruit 48 participants per group.

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Kolmogorov–Smirnov test and histograms. Continuous data are presented as mean $\pm$ standard deviation (SD). Independent samples t tests were used for comparisons between the two groups, and paired t tests for comparisons before and after training within each group. Non-normally distributed variables were expressed as median (IQR) and analyzed with the Mann–Whitney U test for between group comparisons and the Wilcoxon signed-rank test for within group comparisons. Categorical variables were compared using the chi-square test. A two-tailed P value < 0.05 was considered statistically significant.

Results

This study initially enrolled 96 nurse anesthetists between December 15, 2025 and March 31, 2026. Of these, three participants in the control group and one participant in the experimental group did not complete the post-training assessments. Consequently, 92 participants were included in the final analysis, with 45 in the control group and 47 in the experimental group (Fig. 2).

Participant Features

No statistically significant differences were observed between the two groups of nurse anesthetists in terms of age, work experience, and educational background (all $P > 0.05$), indicating demographic homogeneity (Table 1). Before training, there were no statistically significant differences between the groups in the TEAM scores, theoretical scores or skill scores (all $P > 0.05$), demonstrating baseline comparability (Tables 2 and 3).

Table 1
Comparison of age, work experience, and educational background

Age (year)	Control group (<i>n</i> = 45)	Experimental group (<i>n</i> = 47)	<i>t</i> / χ^2	<i>P</i>
	32.78 ± 3.59	33.00 ± 3.41	0.305	0.761
Work experience (year)	9.89 ± 3.28	10.32 ± 3.31	0.626	0.533
Educational background, <i>n</i> (%)			0.482	0.786
Junior College degree	4 (8.89)	6 (12.77)		
Bachelor's degree	37 (82.22)	36 (76.59)		
Master's degree	4 (8.89)	5 (10.64)		

Table 2
Comparison of TEAM scores and three dimension scores

TEAM		Control group (n = 45)	Experimental group (n = 47)	Z	r	P
	Pre-training	36 (35–37)	36 (35–37)	-0.461	-0.048	0.641
	Post-training	37 (35–38)	39 (34.5–40)	-2.999	-0.313	0.003
Z		2.157	2.552			
r		0.350	0.372			
P		0.031	0.011			
Leadership	Pre-training	6 (5–6)	6 (5–6)	0.168	0.018	0.859
	Post-training	6 (5–7)	7 (5–8)	-2.478	-0.258	0.013
Z		-0.746	2.548			
r		-0.124	0.403			
P		0.456	0.011			
Teamwork	Pre-training	24 (23–25)	24 (23–25)	0.707	0.074	0.465
	Post-training	25 (24–26)	26 (23.5–27)	-2.378	-0.248	0.017
Z		2.221	2.328			
r		0.360	0.340			
P		0.026	0.020			
Task management	Pre-training	6 (6–6)	6 (6–6)	0.016	0.002	0.978
	Post-training	7 (5–8)	6 (5–7)	0.576	0.060	0.565
Z		1.042	1.006			
r		0.165	0.170			
P		0.297	0.315			

Table 3
Comparison of theoretical scores and skills scores

Theoretical scores		Control group (<i>n</i> = 45)	Experimental group (<i>n</i> = 47)	<i>t</i>	<i>d</i>	<i>P</i>
	Pre-training	80.56 ± 5.03	80.47 ± 4.69	0.086	0.018	0.931
	Post-training	81.80 ± 4.29	85.40 ± 2.98	-4.697	-0.980	<0.001
<i>t</i>		2.471	4.901			
<i>d</i>		0.368	0.715			
<i>P</i>		0.017	<0.001			
Skills scores	Pre-training	38.13 ± 3.22	38.28 ± 3.21	-0.213	-0.045	0.832
	Post-training	39.31 ± 3.78	41.28 ± 5.34	-2.031	-0.424	0.044
<i>t</i>		2.526	2.698			
<i>d</i>		0.376	0.393			
<i>P</i>		0.015	0.010			

TEAM Scores

After the training, both groups demonstrated significant improvements in the TEAM total scores. In the control group, the TEAM total score increased from 36 (35–37) pre-training to 37 (35–38) post-training ($Z = 2.157, r = 0.350, P = 0.031$). In the experimental group, it improved from 36 (35–37) to 39 (34.5–40) ($Z = 2.552, r = 0.372, P = 0.011$). When comparing the two groups after training, the experimental group achieved a significantly higher TEAM total scores than the control group (median 39 [34.5–40] vs. 37 [35–38]; $Z = -2.999, r = -0.313, P = 0.003$) (Table 2). The effect sizes were medium for the pre-to-post improvements in both groups ($r = 0.350$ and 0.372 in the control and experimental groups, respectively) and for the post-training comparison between the groups ($r = 0.313$).

Regarding the subscales, the control group showed a significant increase only in teamwork scores (median 24 [23–25] vs. 25 [24–26]; $Z = 2.221, r = 0.360, P = 0.026$), while leadership and task management scores did not change significantly (both $P > 0.05$). In the experimental group, both leadership (median 6 [5–6] vs. 7 [5–8]; $Z = 2.548, r = 0.403, P = 0.011$) and teamwork scores (median 24 [23–25] vs. 26 [23.5–27]; $Z = 2.328, r = 0.340, P = 0.020$) improved significantly, whereas task management remained unchanged ($P = 0.315$). Post-training between-group comparisons revealed significantly higher leadership and teamwork scores in the experimental group (leadership: $Z = -2.478, r$

= 0.258, $P = 0.013$; teamwork: $Z = -2.378$, $r = -0.248$, $P = 0.017$). In contrast, task management scores did not differ between groups after training ($P = 0.565$) (Table 2; Fig. 3).

Theoretical and skill scores

Both groups demonstrated significant improvements in theoretical knowledge after the training. In the control group, the mean score increased from 80.56 ± 5.03 pre-training to 81.80 ± 4.29 post-training (mean difference 1.24, 95% CI 0.229 to 2.260; $t = 2.471$, $P = 0.017$). In the experimental group, it improved from 80.47 ± 4.69 to 85.40 ± 2.98 (mean difference 4.93, 95% CI 2.909 to 6.963; $t = 4.901$, $P < 0.001$). After the training, the experimental group achieved a significantly higher score than the control group (85.40 ± 2.98 vs. 81.80 ± 4.29 ; mean difference 3.60, 95% CI - 5.141 to - 2.068; $t = -4.697$, $P < 0.001$). The effect sizes were medium-to-large for the pre-to-post improvement within the experimental group (Cohen's $d = 0.715$) and large for the post-training between-group comparison (Cohen's $d = 0.980$), while a small-to-medium effect was observed in the control group (Cohen's $d = 0.368$) (Table 3; Fig. 4).

Regarding practical skill performance, both groups exhibited significant improvements from pre- to post-training. In the control group, the mean score increased from 38.13 ± 3.22 to 39.31 ± 3.78 (mean difference 0.15, 95% CI 0.238 to 2.118; $t = 2.526$, $P = 0.015$). In the experimental group, it improved from 38.28 ± 3.21 to 41.28 ± 5.34 (mean difference 3.01, 95% CI 0.76 to 5.24; $t = 2.698$, $P = 0.010$). Following the training, the experimental group achieved significantly higher scores than the control group (41.28 ± 5.34 vs. 39.31 ± 3.78 ; mean difference 1.97, 95% CI 0.06 to 3.88; $t = -2.031$, $P = 0.044$). The effect sizes were small-to-medium for the pre-to-post improvements (Cohen's $d = 0.376$ in the control group; $d = 0.393$ in the experimental group) and medium for the post-training comparison between the groups (Cohen's $d = -0.424$) (Table 3; Fig. 4).

Student satisfaction and self-confidence in learning

After the training, the experimental group reported higher overall learning satisfaction than the control group (54.64 ± 4.47 vs. 52.67 ± 4.76 ; mean difference 1.97, 95% CI 0.06 to 3.89, $P = 0.044$). Self-confidence in learning was also significantly higher in the experimental group (33.43 ± 2.51 vs. 32.11 ± 2.53 ; mean difference 1.32, 95% CI 0.27 to 2.36, $P = 0.014$). No significant difference was observed between the two groups for the student satisfaction subscale (21.21 ± 2.23 vs. 20.56 ± 2.33 ; mean difference 0.65, 95% CI 0.29 to 1.60, $P = 0.170$) (Table 4; Fig. 5).

Table 4
Comparison of student satisfaction and self-confidence in learning

Self-confidence in learning	Control group (<i>n</i> = 45)	Experimental group (<i>n</i> = 47)	<i>t</i>	<i>d</i>	<i>P</i>
	32.11 ± 2.53	33.43 ± 2.51	-2.499	-0.521	0.014
Student satisfaction	20.56 ± 2.33	21.21 ± 2.23	-1.382	-0.289	0.170
Total	52.67 ± 4.76	54.64 ± 4.47	-2.047	-0.427	0.044

Discussion

This study investigated the application efficacy of the FC-PBL teaching method in perioperative anaphylaxis management training for nurse anesthetists. The results demonstrated that, compared with traditional lecture-based instruction, FC-PBL significantly improved team emergency performance, with notably higher teamwork and leadership scores in the experimental group, whereas task management did not differ between groups. Significant improvements were also observed in theoretical knowledge and practical skill scores. Student satisfaction did not differ significantly between the two groups, while the experimental group reported significantly higher self-confidence in learning.

Given the diagnostic complexity, narrow therapeutic window, and high demand for coordinated action in perioperative anaphylaxis, proficient teamwork is indispensable for patient safety [27–29]. The TEAM was chosen as the primary outcome because it is a widely recommended measurement for assessing non-technical performance with established reliability and sensitivity to training effects [22, 30, 31]. At baseline, TEAM scores did not differ between groups, confirming comparability. Both groups improved significantly after training, however, the FC-PBL model achieved markedly higher total scores. This advantage was driven by significantly higher scores in the teamwork and leadership domains, whereas task management scores did not differ significantly between groups. These findings suggest that the FC-PBL approach better equips nurse anesthetists with the teamwork and leadership skills essential for managing perioperative crises, likely through fostering active pre-class preparation and collaborative in-class problem solving. These results align with previous studies demonstrating that the FC-PBL model enhances team performance and clinical decision making in medical trainees [17, 19, 32], and support its value in developing high functioning emergency teams.

The absence of a significant difference between groups in task management warrants consideration. One possible explanation is that the task management subscale comprises only two items, which may limit its sensitivity to detect subtle differences or reduce statistical power given the moderate sample size. Furthermore, the design of this study, in which both groups received a substantial amount of simulation training with structured debriefing, may have contributed to comparable improvements in task management. This subscale captures structured processes such as protocol adherence and prioritization, which are likely to benefit from simulation practice. Since such practice was present in

both groups, it may have produced similar gains, thereby attenuating any incremental effect of the pre-class and PBL components. Future studies with larger samples or more refined task management assessments may be needed to clarify this finding.

Traditional lecture-based continuing education often falls short in fostering the critical thinking and hands-on competence needed for perioperative emergencies [33–36]. In the present study, the FC-PBL approach significantly improved both theoretical knowledge and practical skill scores, with medium effect sizes for the post training comparison between the groups. FC is an active student-centered teaching method that enhances students' participation and promotes active learning, thereby improving the teaching quality within the classroom [37, 38]. In nursing education, PBL has been shown to enhance nurses' clinical reasoning and decision-making abilities [39]. Consistent with these findings, previous research has demonstrated that the FC-PBL teaching method can enhance medical graduate students' overall understanding of professional knowledge, promote interaction between teachers and students, and improve teamwork skills [19]. Similarly, a study in nephrology nursing interns found that PBL combined with flipped classroom significantly improved theoretical knowledge mastery, practical skill levels, and self-learning ability [4]. Collectively, these results indicate that the FC-PBL approach enhances theoretical and practical competencies, making it an efficient strategy for continuing education in anesthesia nursing.

In addition to objective performance metrics, learners' perceptions of the educational intervention are critical for evaluating its feasibility and acceptability [40, 41]. In the present study, the overall student satisfaction and self-confidence in learning score was significantly higher in the experimental group than in the control group, whereas the student satisfaction subscale did not differ significantly between groups. This suggests that certain specific facets of satisfaction were similarly appreciated by both groups, although the global educational experience was perceived more favorably by the experimental group. One possible explanation is that the traditional lecture approach, when delivered with high quality and accompanied by hands-on simulation practice, can also generate a positive learning experience. Additionally, because student satisfaction was a secondary outcome, the sample size may have lacked sufficient power to detect a small effect on the subscale.

In contrast, the experimental group reported significantly higher self-confidence in learning. This improvement can be attributed to the FC-PBL model's ability to shift from passive knowledge reception to active problem solving [42]. By acquiring foundational knowledge through pre-class micro-videos, learners can dedicate in-class time to high-yield activities such as analyzing real clinical cases and participating in simulated scenarios. This approach not only reduces cognitive load but also allows students to apply theory in a risk-free environment, thereby enhancing their perceived competence and confidence. Consequently, this pedagogical shift not only improves immediate learning outcomes but also cultivates the psychological readiness required for high-stakes emergency management.

Limitations

Several limitations should be acknowledged in this study. First, this was a single-center study, and the intervention was confined to a single educational topic (perioperative anaphylaxis management). These factors may limit the generalizability of the findings. Second, standardized training curricula for nurse anesthetists are still under development, and institutional training frameworks vary considerably across hospitals. This heterogeneity may affect the applicability and reproducibility of the FC-PBL model in different clinical settings. Third, outcomes were assessed only two weeks post-training. The long-term retention of knowledge and skills, as well as the transfer of learning to actual clinical practice, remains to be determined. Future multicenter studies with larger cohorts, extended follow-up, and broader topic coverage are warranted to further validate the effectiveness of this teaching approach.

Conclusion

The FC-PBL is an effective and well-accepted teaching method for perioperative anaphylaxis training in nurse anesthetists. This approach significantly enhances nurse anesthetists' competencies in rapid identification, standardized management, and collaborative response to perioperative anaphylaxis, while also improving their self-confidence in learning. These findings support the integration of FC-PBL into continuing education programs for anesthesia nursing.

Abbreviations

PBL	
Problem-Based Learning	
FC	
Flipped classroom	
NLN	
National League for Nursing	
TEAM	
Team Emergency Assessment Measure	
ICN	
International Council of Nurses	
SD	
Standard deviation	
IQR	
Interquartile range	
CI	
Confidence interval	

Declarations

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Author contributions

Yan-Ling Ren and Fei Xing designed the study. Yan-ling Ren, Hao-Yong Zhang, Ming-Zhu Jing, and Jia-Qi Chen acquired the data. Hao-Yong Zhang, Ming-Zhu Jing, and Jia-Qi Chen rated the team performance. Yan-Ling Ren drafted the manuscript. Wei Zhang and Fei Xing critically revised the manuscript. Fei Xing supervised the overall study. All authors read and approved the final manuscript.

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Data availability

The data and materials used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the First Affiliated Hospital of Zhengzhou University (2025-KY-1700-001) and was registered at the Chinese Clinical Trial Registry (<http://www.chictr.org.cn/>; December 9, 2025, ChiCTR2500114190). The study protocol followed the CONSORT guidelines. Additionally, the researchers explained to the participants that all information was confidential, and they could withdraw from the study anytime. Informed consent was sought from all study participants before data collection. The work described has been carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Pouessel G, Dribin TE, Tacquard C, Tanno LK, Cardona V, Worm M, Deschildre A, Muraro A, Garvey LH, Turner PJ. Management of Refractory Anaphylaxis: An Overview of Current Guidelines. *Clin Exp Allergy*. 2024;54(7):470–88. <https://doi.org/10.1111/cea.14514>.
2. Banerji A, Bhattacharya G, Huebner E, Fu X, Camargo CA Jr, Guyer A, Kuhlen JL Jr, Blumenthal KG. Perioperative Allergic Reactions: Allergy Assessment and Subsequent Anesthesia. *J Allergy Clin Immunol Pract*. 2021;9(5):1980–91. <https://doi.org/10.1016/j.jaip.2020.11.025>.
3. Garvey LH, Ebo DG, Mertes PM, Dewachter P, Garcez T, Kopac P, Laguna JJ, Chiriac AM, Terreehorst I, Voltolini S. An EAACI position paper on the investigation of perioperative immediate hypersensitivity reactions. *Allergy*. 2019;74(10):1872–84. <https://doi.org/10.1111/all.13820>.
4. International Council of Nurses (ICN). Guidelines on Advanced Practice Nursing - Nurse Anesthetists. https://www.icn.ch/sites/default/files/2023-04/ICN_Nurse-Anaesthetist-Report_EN_WEB.pdf
5. Pann KJ, Buchner VK, Eßl-Maurer R, Bacher T, Glarcher M, Ewers A. International competencies of nurses with advanced practice in anesthesia nursing: An integrative review. *Int J Nurs Stud Adv*. 2025;8:100319. <https://doi.org/10.1016/j.ijnsa.2025.100319>.
6. Rathore TS, Sidhu A, Kaur M. The Arc of Nurse Anesthesia: From Battlefield Origins to Future Innovation. *Crit Care Nurs Clin North Am*. 2026;38(2):291–8. <https://doi.org/10.1016/j.cnc.2026.02.007>.
7. Kandra K, Vennam P. The Active Classroom: A Narrative Review of Active Teaching Methods and the Flipped Classroom Model in Graduate Medical Education. *Cureus*. 2025;17(11):e98186. <https://doi.org/10.7759/cureus.98186>.
8. Hedlund J, Blomberg K, Hjelmqvist H, Jaensson M. Student nurse anesthetists' learning during clinical practice: a mixed-methods study. *BMC Med Educ*. 2026;26(1):1198. <https://doi.org/10.1186/s12909-026-09944-8>.
9. Tamura T, Sakai T, Henker R, O'Donnell JM. Certified registered nurse anesthetist and anesthesiologist assistant education programs in the United States. *Nagoya J Med Sci*. 202;83(3):609–626. <https://doi.org/10.18999/nagjms.83.3.609>
10. Andargeery SY, Bahri HA, Alhalwani RA, Alahmedi SH, Ali WH. Using a flipped teaching strategy in undergraduate nursing education: students' perceptions and performance. *BMC Med Educ*. 2024;24(1):926. <https://doi.org/10.1186/s12909-024-05749-9>.
11. Wang Y, Su WJ, Li JC, Yang MC. Flipped Classroom Model in the standardized training of anesthesiology residents. *Asian J Surg*. 2023;46(11):4899–900. <https://doi.org/10.1016/j.asjsur.2023.05.177>.
12. Doğan DA, Serpici A. Nursing Students' Fear of Negative Evaluation and Perceptions of Clinical Decision-Making. *J Nurs Educ*. 2023;62(6):325–31. <https://doi.org/10.3928/01484834-20221011-02>.
13. Kulo V, Cestone C. A Bibliometric Analysis of the 100 Most Cited Articles on Problem-Based Learning in Medical Education. *Med Sci Educ*. 2023;33(6):1409–26.

<https://doi.org/10.1007/s40670-023-01893-x>.

14. Merisier S, Larue C, Boyer L. How does questioning influence nursing students' clinical reasoning in problem-based learning? A scoping review. *Nurse Educ Today*. 2018;65:108–15. <https://doi.org/10.1016/j.nedt.2018.03.006>.
15. Compton RM, Owilli AO, Norlin EE, Hubbard Murdoch NL. Does problem-based learning in Nursing Education Empower Learning? *Nurse Educ Pract*. 2020;44:102752. <https://doi.org/10.1016/j.nepr.2020.102752>.
16. Avraam D, Televantou I, Albert AP, Hitchings AW, Nicolaou SA, Papageorgiou A, McCrorie P, Nicolaou P. Exploring the relationship between learning approaches and problem-based learning: insights from a longitudinal study in medical students. *BMC Med Educ*. 2025;25(1):619. <https://doi.org/10.1186/s12909-025-07171-1>.
17. Chi M, Wang N, Wu Q, Cheng M, Zhu C, Wang X, Hou Y. Implementation of the Flipped Classroom Combined with Problem-Based Learning in a Medical Nursing Course: A Quasi-Experimental Design. *Healthc (Basel)*. 2022;10(12):2572. <https://doi.org/10.3390/healthcare10122572>.
18. Ni ZH, Huang J, Yang DP, Wang J. Nursing students' experience of flipped classroom combined with problem-based learning in a paediatric nursing course: a qualitative study. *BMC Nurs*. 2024;23(1):88. <https://doi.org/10.1186/s12912-024-01744-z>.
19. Wang A, Xiao R, Zhang C, Yuan L, Lin N, Yan L, Wang Y, Yu J, Huang Q, Gan P. Effectiveness of a combined problem-based learning and flipped classroom teaching method in ophthalmic clinical skill training. *BMC Med Educ*. 2022;22(1):487. <https://doi.org/10.1186/s12909-022-03538-w>.
20. Hopewell S, Chan AW, Collins GS, Hróbjartsson A, Moher D, Schulz KF, et al. CONSORT 2025 Statement: updated guideline for reporting randomised trials. *BMJ*. 2025;388:e081123. <https://dx.doi.org/10.1136/bmj-2024-081123>.
21. Eppich W, Cheng A. Promoting Excellence and Reflective Learning in Simulation (PEARLS): development and rationale for a blended approach to health care simulation debriefing. *Simul Healthc*. 2015;10(2):106–15. <https://doi.org/10.1097/SIH.0000000000000072>.
22. Freytag J, Stroben F, Hautz WE, Schaubert SK, Kämmer JE. Rating the quality of teamwork-a comparison of novice and expert ratings using the Team Emergency Assessment Measure (TEAM) in simulated emergencies. *Scand J Trauma Resusc Emerg Med*. 2019;27(1):12. <https://doi.org/10.1186/s13049-019-0591-9>.
23. Chiu PW, Chu SC, Yang CH, Lee HF, Hung HM, Hsu HC. Peer-assisted learning in critical care: a simulation-based approach for postgraduate medical training. *Med Educ Online*. 2025;30(1):2497333. <https://doi.org/10.1080/10872981.2025.2497333>.
24. Chua WL, Tee A, Hassan NB, Jones D, Tam WWS, Liaw SY. The development and psychometric evaluation of the Clinicians' Attitudes towards Responding and Escalating care of Deteriorating patients scale. *Aust Crit Care*. 2021;34(4):340–9. <https://doi.org/10.1016/j.aucc.2020.08.008>.
25. Freytag J, Stroben F, Hautz WE, Eisenmann D, Kämmer JE. Improving patient safety through better teamwork: how effective are different methods of simulation debriefing? Protocol for a pragmatic,

- prospective and randomised study. *BMJ Open*. 2017;7(6):e015977.
<https://doi.org/10.1136/bmjopen-2017-015977>.
26. National League for Nursing Descriptions of Available Instruments [Internet]. 2020. [cited 2020 Sep 24]. Available from: <http://www.nln.org/professional-development-programs/research/tools-and-instruments/descriptions-of-available-instruments>
 27. Pouessel G, Trochu C, Chagnon F, Diesnis R, Leteurtre S, Deschildre A, French Group for Paediatric Intensive Care and Emergencies (FGPICE). Severe and refractory anaphylaxis in pediatric intensive care unit. *Allergy*. 2023;78(8):2315–8. <https://doi.org/10.1111/all.15712>.
 28. Turner PJ, Arasi S, Ballmer-Weber B, Baseggio Conrado A, Deschildre A, Gerdtts J, Halken S, Muraro A, Patel N, Van Ree R. Risk factors for severe reactions in food allergy: Rapid evidence review with meta-analysis. *Allergy*. 2022;77(9):2634–52. <https://doi.org/10.1111/all.15318>.
 29. Schmutz JB, Meier LL, Manser T. How effective is teamwork really? The relationship between teamwork and performance in healthcare teams: a systematic review and meta-analysis. *BMJ Open*. 2019;9(9):e028280. <https://doi.org/10.1136/bmjopen-2018-028280>.
 30. Karlgren K, Dahlström A, Birkestam A, Drevstam Norling A, Forss G, Andersson Franko M, Cooper S, Leijon T, Paulsson C. The TEAM instrument for measuring emergency team performance: validation of the Swedish version at two emergency departments. *Scand J Trauma Resusc Emerg Med*. 2021;29(1):139. <https://doi.org/10.1186/s13049-021-00952-9>.
 31. Armijo-Rivera S, Ferrada-Rivera S, Aliaga-Toledo M, Pérez LA. Application of the Team Emergency Assessment Measure Scale in undergraduate medical students and interprofessional clinical teams: validity evidence of a Spanish version applied in Chile. *Front Med (Lausanne)*. 2023;10:1256982. <https://doi.org/10.3389/fmed.2023.1256982>.
 32. Lin Y, He X, Dai W, Tan W, Xu Y. The application and effectiveness of PBL combined with MDT and flipped classroom teaching method in acute coronary syndrome education for undergraduate medical students. *BMC Med Educ*. 2025;25(1):1559. <https://doi.org/10.1186/s12909-025-08150-2>.
 33. Alamoudi AA, Al Shawwa LA, Gad H, Tekian A. Team-based learning versus traditional didactic lectures in teaching clinical biochemistry at King Abdulaziz University; learning outcomes and student satisfaction. *Biochem Mol Biol Educ*. 2021;49(4):546–59. <https://doi.org/10.1002/bmb.21501>.
 34. Cai L, Li YL, Hu XY, Li R. Implementation of flipped classroom combined with case-based learning: A promising and effective teaching modality in undergraduate pathology education. *Med (Baltim)*. 2022;101(5):e28782. <https://doi.org/10.1097/MD.00000000000028782>.
 35. Mardian AS, Villarroel L, Kemper L, Quist HE, Hanson ER. Didactic dissonance-embracing the tension between classroom and clinical education. *Front Med (Lausanne)*. 2023;10:1197373. <https://doi.org/10.3389/fmed.2023.1197373>.
 36. Nguyen W, Fromer I, Remskar M, Zupfer E. Development and Implementation of Video-Recorded Simulation Scenarios to Facilitate Case-Based Learning Discussions for Medical Students' Virtual

- Anesthesiology Clerkship. MedEdPORTAL. 2023;19:11306. https://doi.org/10.15766/mep_2374-8265.11306.
37. Divjak B, Rienties B, Iniesto F, Vondra P, Žižak M. Flipped classrooms in higher education during the COVID-19 pandemic: findings and future research recommendations. *Int J Educ Technol High Educ*. 2022;19(1):9. <https://doi.org/10.1186/s41239-021-00316-4>.
 38. Shuai L, Huiwen W, Shihao D, Li J. The application of flipped classroom combined with team-based learning in the orthopedic clinical teaching. *Med (Baltim)*. 2023;102(43):e35803. <https://doi.org/10.1097/MD.00000000000035803>.
 39. Bolado GN, Atinafu Ataro B, Ersino Kebamo T, Shibabaw Ayana A, Mimani Minuta W. Nurse educators' challenges of problem-based learning implementation at Ethiopian public universities: A phenomenological qualitative study. *PLoS ONE*. 2025;20(6):e0325976. <https://doi.org/10.1371/journal.pone.0325976>.
 40. Abarca LLM, Barros ALBL, Baptista RCN, Batista REA, Lopes JL. Effect of video on satisfaction and self-confidence in simulation training: a randomized clinical trial. *Rev Bras Enferm*. 2023;76(3):e20220366. <https://doi.org/10.1590/0034-7167-2022-0366>.
 41. Übelacker A, Parisch H, Novak J, Ernst M, Roszipal B. Evaluating student satisfaction and self-confidence across a scaffolded simulation curriculum in undergraduate nursing education. *Front Med (Lausanne)*. 2026;13:1842182. <https://doi.org/10.3389/fmed.2026.1842182>.
 42. Yang Y, Xue J, Hu L, Fang K, Wei C, Wu C, Jin H. A combined PBL and flipped classroom intervention enhances self-directed learning ability and empathy in ophthalmology undergraduates. *Sci Rep*. 2026;16(1):11696. <https://doi.org/10.1038/s41598-026-47584-6>.

Figures

FC-PBL Anesthesia Nursing Approach

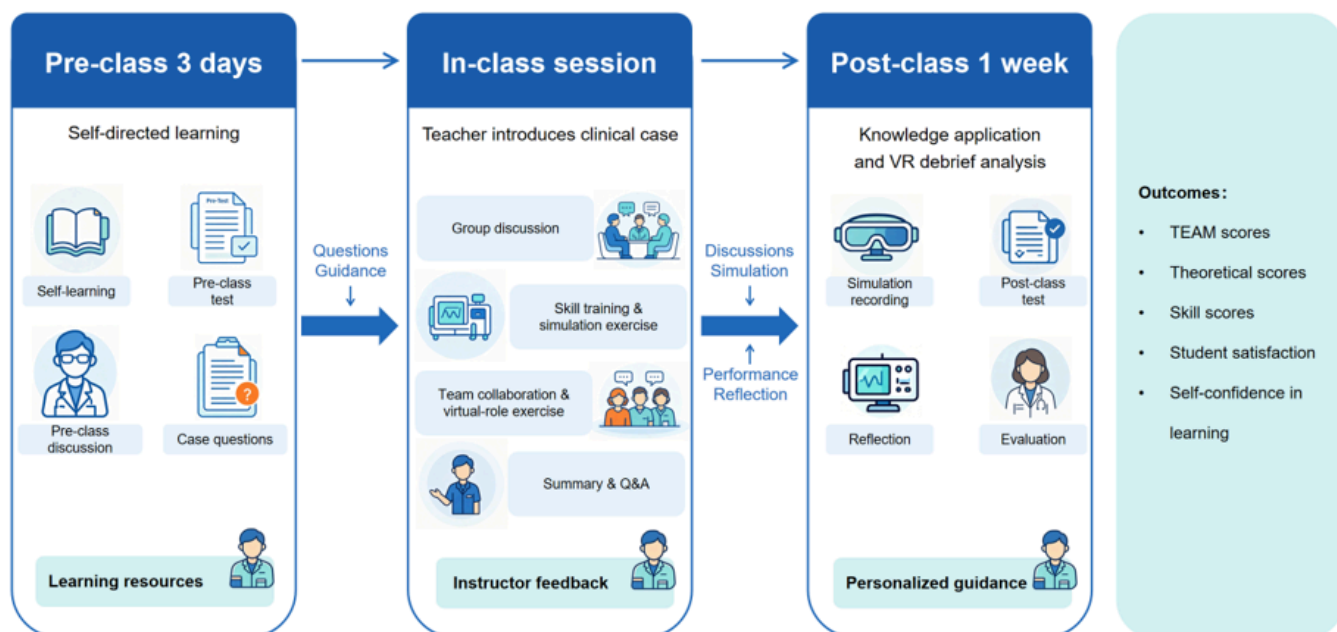


Figure 1

Overview of the FC-PBL approach. The pre-class phase began 3 days before the session, during which students engaged in self-directed learning using provided resources (micro-videos, electronic textbooks, and clinical case materials), completed an online test, and prepared discussion and questions. The in-class phase involved group discussion with assigned roles, skill training and simulation exercises, and a summary with Q&A followed by instructor feedback. The post-class phase was completed within one week, including review of simulation recordings, post-class test, reflection submission, and individualized training with personalized guidance. FC, flipped classroom; PBL, problem-based learning; Q&A, question and answer.

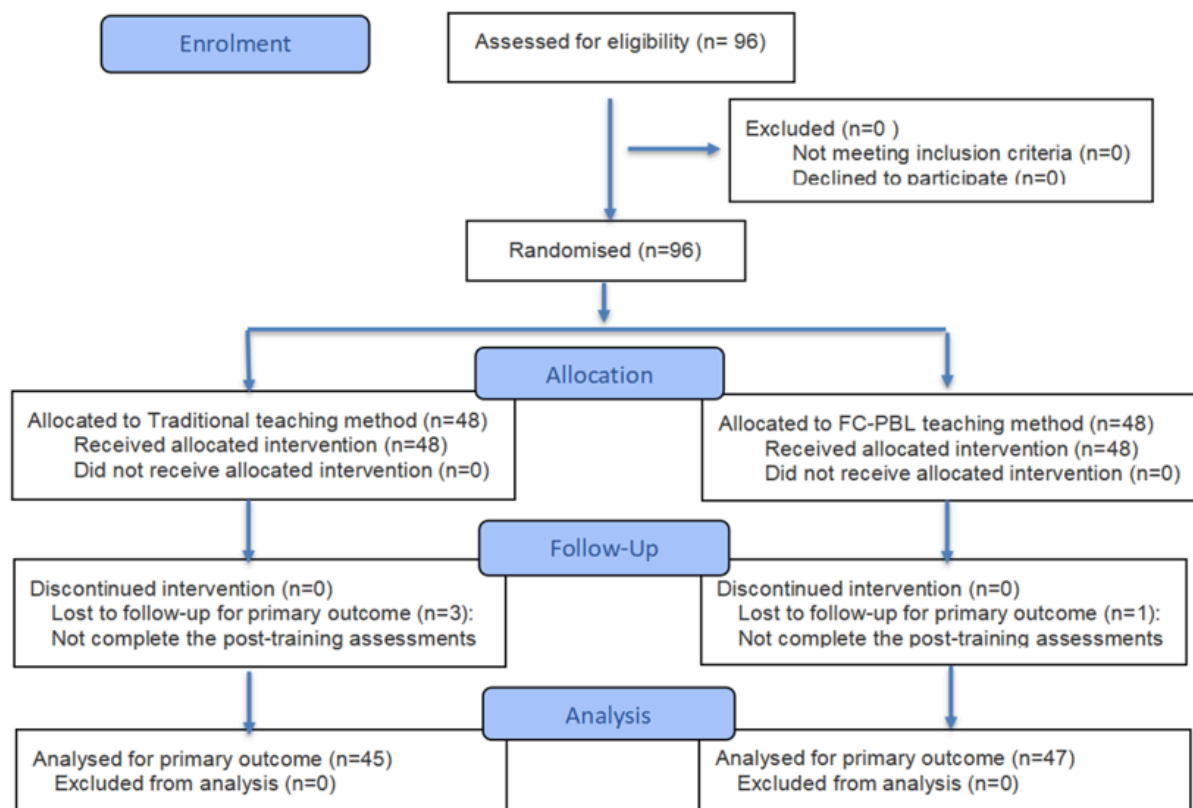


Figure 2

Flow of the study procedure.

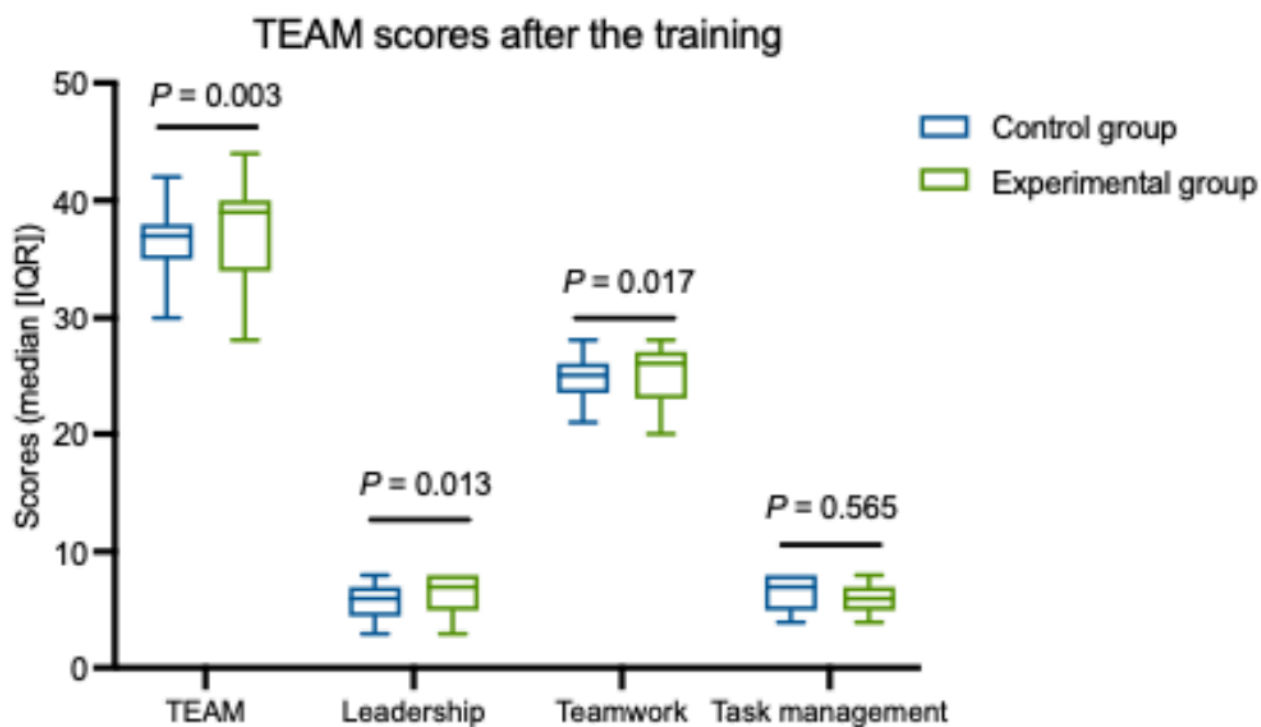


Figure 3

TEAM total and subscale scores in the control and experimental groups after training.Box plots display the median (midline), interquartile range (box boundaries), and range (whiskers). TEAM total, leadership, and teamwork scores were significantly higher in the experimental group than in the control group (all $P < 0.05$), whereas task management did not differ significantly between groups.

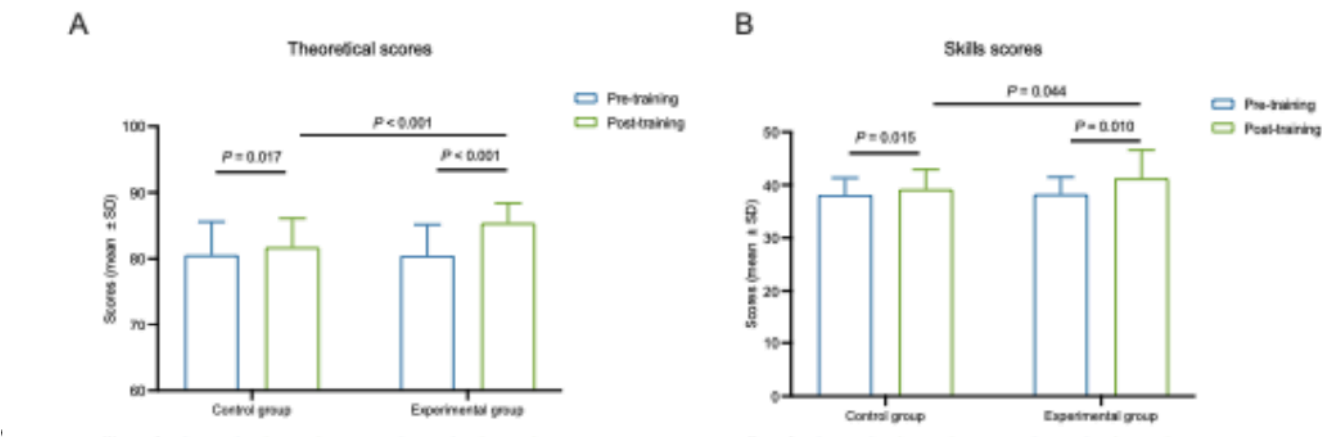


Figure 4

Theoretical knowledge and practical skill scores in the control and experimental groups pre-training and post-training. (A) Theoretical scores. (B) Skill scores. Bars represent mean scores, and error bars indicate standard deviations. Both groups showed significant improvements after training, and the experimental group achieved significantly higher scores than the control group in both assessments (all $P < 0.05$).

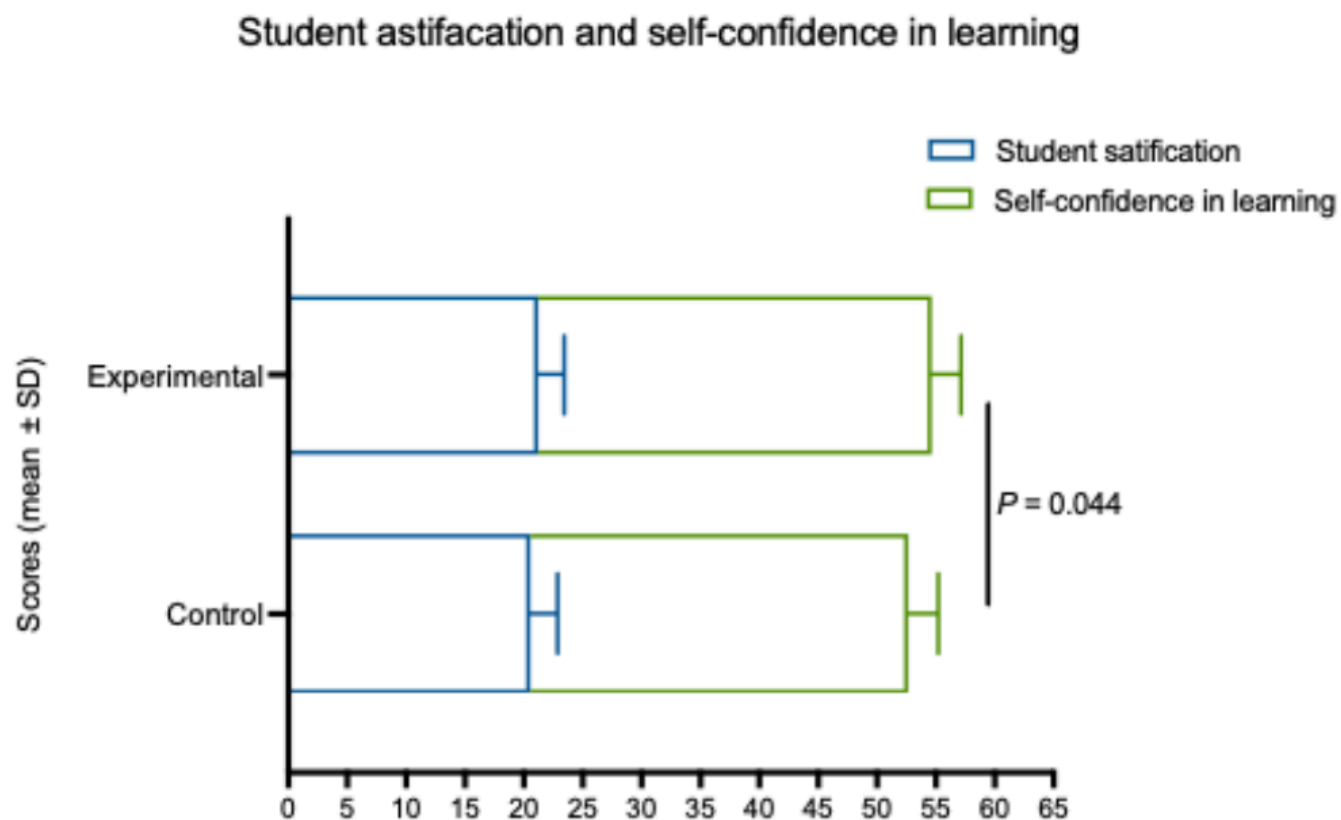


Figure 5

Student satisfaction and self-confidence in learning scores in the control and experimental groups. Stacked horizontal bars display the mean student satisfaction score (blue) and the mean self-confidence in learning score (green). The total score (sum of the two subscales) was significantly higher in the experimental group than in the control group ($P < 0.05$).