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ORIGINAL RESEARCH

# Effectiveness of the BOPPPS-MDT Model in Enhancing ECMO Training for ICU Staff: A Randomized Controlled Trial Assessing Knowledge, Skills, and Teamwork Outcomes

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**Background:** Extracorporeal membrane oxygenation (ECMO) is a life-saving therapy for critically ill patients, and effective training for ICU staff is essential. This study aimed to evaluate the effectiveness of the BOPPPS-MDT (Bridge-in, Objectives, Pre-assessment, Participatory Learning, Post-assessment, and Summary model integrated with Multidisciplinary Team) teaching model in enhancing ECMO training for ICU staff.

**Methods:** A total of 108 ICU interns with diverse educational backgrounds and majors were randomly assigned to two groups: 54 in the control group and 54 in the experimental group. The experimental group received ECMO training using the BOPPPS-MDT model, while the control group received traditional training. Both groups underwent theoretical knowledge tests, performance evaluations, and satisfaction surveys.

**Results:** There were no significant differences in baseline characteristics between the two groups. The experimental group scored significantly higher than the control group in 13 key theoretical knowledge areas ($P < 0.05$), case analysis, teamwork, and overall performance. The total score of the experimental group was significantly higher ($P < 0.05$). Cronbach's α ranged from 0.757 to 0.905, confirming high reliability. The satisfaction rate for the BOPPPS-MDT method was 92.17%, significantly higher than the 75.42% for the traditional method ($P = 0.001$). The BOPPPS-MDT method enhanced engagement, interactivity, learning interest, and teamwork.

**Conclusion:** The BOPPPS-MDT teaching model significantly improved ECMO training outcomes and student satisfaction compared to traditional methods.

**Keywords:** BOPPPS-MDT teaching model, intensive care unit, oxygenation of extracorporeal membrane oxygenation, teaching effectiveness, learning outcomes, satisfaction survey

## Introduction

Extracorporeal membrane oxygenation (ECMO) has become an essential life-support technique in the ICU for managing critically ill patients, particularly those with acute respiratory distress syndrome (ARDS), cardiogenic shock, or cardiac arrest.[1] In clinical practice, the timely and effective use of ECMO can be lifesaving, yet its successful application requires healthcare professionals to master a highly complex set of skills, including device setup, monitoring, patient parameter adjustments, and rapid response to emergencies. These intricate operations are not only technically demanding but also carry high stakes, as errors in ECMO management can lead to severe complications or even fatal outcomes. Traditional ECMO training methods, such as lectures and basic hands-on practice, are often insufficient for addressing these challenges. While these methods can provide foundational knowledge, they frequently fail to simulate the



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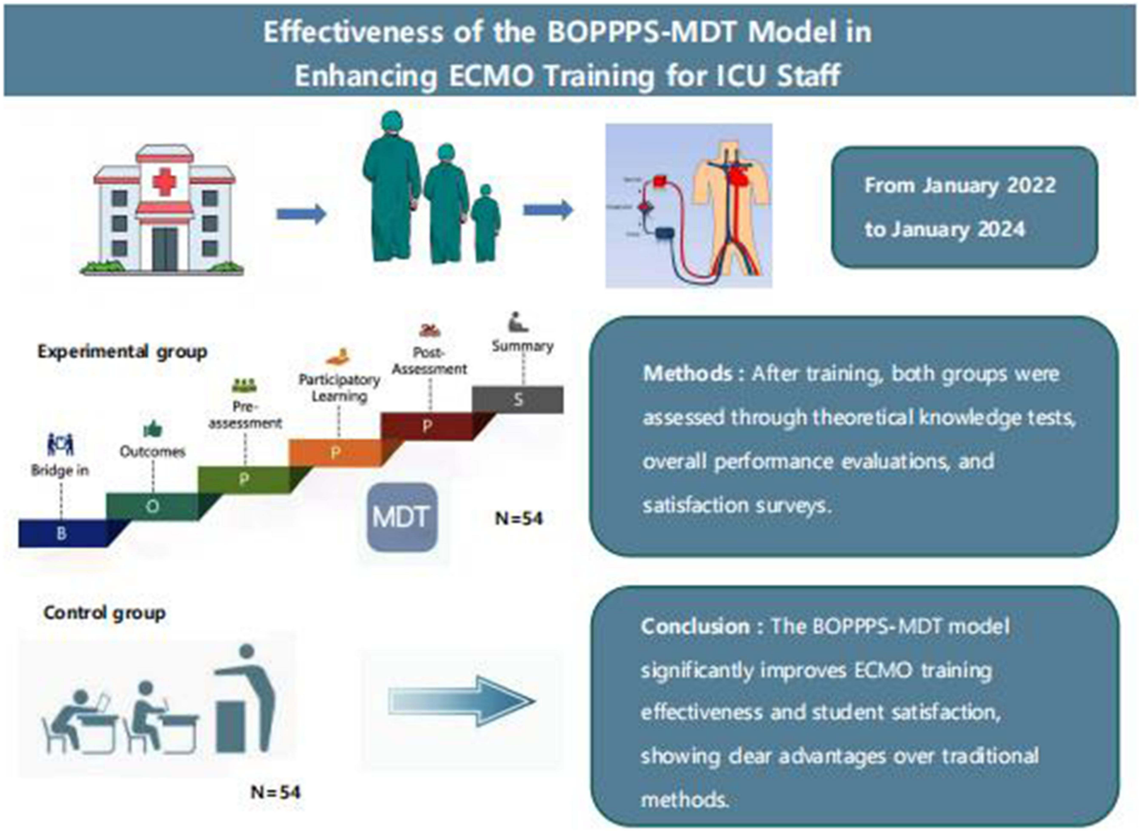
**Graphical Abstract**




complexity and urgency of real-world ECMO scenarios. For example, traditional lectures emphasize theoretical concepts but lack interactive engagement, making it difficult for trainees to translate knowledge into practice. Similarly, hands-on training is often limited to static settings, with inadequate opportunities for practicing critical decision-making and team-based responses under pressure. These limitations result in a prolonged learning curve, inconsistent skill acquisition, and reduced confidence among healthcare professionals.[2] Therefore, improving the quality and efficiency of ECMO training is a pressing clinical need, as it directly impacts the safety and outcomes of critically ill patients.

The BOPPPS model, known for its structured and progressive teaching strategy, has been widely adopted in various educational settings.[3] It consists of six elements: "B" for Bridge-in, "O" for Objective, "P" for preassessment, "P" for Participatory Learning, "P" for Postassessment, and "S" for Summary.[4] These components guide the design and organization of classroom activities, facilitating the introduction of new concepts, promoting student engagement, and reinforcing learning during the summary phase. The goal is to stimulate student interest and foster deeper understanding.[5] The MDT teaching method, on the other hand, emphasizes the importance of interdisciplinary collaboration, experience sharing, and collective wisdom. It offers a richer, more comprehensive perspective on learning and training.[6] While some studies have explored the effectiveness of simulation-based training in ECMO, most focus solely on isolated technical skills, without integrating interdisciplinary collaboration or real-time decision-making in a high-stakes environment. Additionally, limited research has explored the application of the BOPPPS model and the MDT approach together in ECMO training, with most studies focusing separately on one of these methods rather than combining them to enhance engagement and learning outcomes. Thus, the integration of these two methods, BOPPPS and MDT, into a cohesive ECMO training program remains largely unexplored.

By combining these two teaching methods, this study seeks to develop a more effective and systematic ECMO training model, thereby improving the learning outcomes of interns in mastering ECMO skills. In addition to evaluating the teaching effectiveness during the training process, the study will also comprehensively assess interns' ECMO operational proficiency, teamwork capabilities, and ability to handle unexpected situations post-training.

# Materials and Methods

## General Data

The study was conducted from September 2022 to September 2023 in Wuhan No.6 hospital. The sample size determination and study design were conducted to ensure statistical rigor and minimize bias. A total of 108 interns rotating through the ICU of the hospital were included as study participants. Participants were randomly assigned to either the experimental group (BOPPPS-MDT teaching model) or the control group (traditional teaching method) using computer-generated random numbers. Twelve rotation batches, each consisting of 9 participants, were divided into two groups, with 6 batches (54 participants) in each group. The sample size was calculated based on effect size estimation, statistical power, and significance level. A preliminary pilot study provided the effect size for the primary outcome measures, which was then utilized for a power analysis using GPower software (Version 3.1). The statistical power was set at 0.80, with a significance level of 0.05. To maintain consistency in teaching quality, both groups were supervised by the same two experienced attending physicians. Due to the inherent differences in the teaching methods, blinding of the instructors was not feasible. However, all outcome measures, including theoretical knowledge tests, overall performance evaluations, and satisfaction surveys, were assessed by independent evaluators. These evaluators were third-party personnel who were not involved in the teaching process and were blinded to group assignments. Contamination between groups was minimized by designing the rotation schedule to prevent overlap between participants in the observation and control groups during the same teaching sessions. Standardized teaching materials were utilized to ensure consistency in theoretical content across all participants.

## Inclusion and Exclusion Criteria

Inclusion criteria: Undergraduate, master's, or doctoral students rotating or interning in the ICU who were willing to participate in the study, had no severe underlying diseases (eg, disabilities, malignancies, or cognitive impairments), did not have unhealthy habits such as heavy alcohol consumption or smoking, and were able to follow instructions and complete the study requirements. Exclusion criteria: Students who were unwilling to participate in the study or did not meet the inclusion criteria at the start of the study were excluded. All randomized participants were included in the final analysis.

## Methods

This study was approved by the Ethics Committee of Wuhan No. 6 hospital and is part of a registered randomized controlled trial (RCT) with the registration number ChiCTR-ONC-17011730. All participants provided informed consent, and their participation was voluntary. The control group received traditional teaching methods. The instructor demonstrated and explained the basic principles and functions of ECMO, its indications, equipment components, operational steps, precautions, clinical practice, case discussions, and complication management. Students were asked questions, and a Q&A session followed the class. The intervention was conducted over a one-month training period, with two sessions per week. Each session lasted approximately 2 hours, ensuring ample time for theoretical instruction, hands-on practice, and multidisciplinary case discussions. As per the CONSORT guidelines, a flow diagram illustrating the study design and participant progression is provided below (Figure 1). The primary outcomes of this study were the improvements in theoretical knowledge and total scores, specifically in key theoretical areas and overall performance, following the implementation of the BOPPPS-MDT model. Secondary outcomes included case analysis performance, teamwork skills, and student satisfaction, with a focus on increased participation, interactivity, and learning outcomes.

The experimental group received teaching using the BOPPPS-MDT model. The implementation process was as follows: ①Bridge-in: In the Bridge-in (B) phase, a real clinical case of successful ECMO intervention was used to bridge the gap between theory and practice. This case underscored the crucial role of ECMO in patient rescue, effectively

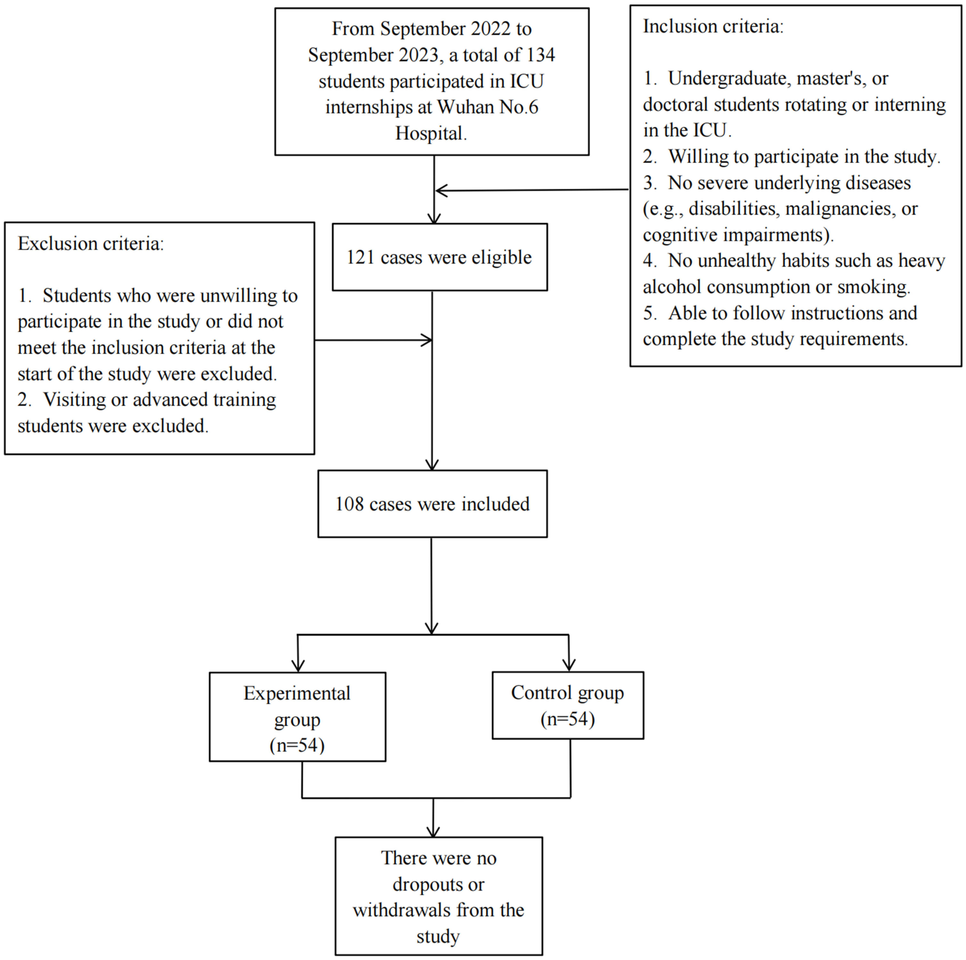



**Figure 1** Study flow diagram of participant enrollment and group allocation:From September 2022 to September 2023, a total of 134 students participated in ICU internships at Wuhan No.6 hospital. After eligibility assessment, 121 cases met the inclusion criteria, and 108 participants were ultimately included in the study. These participants were randomly assigned to the experimental group (n=54) and the control group (n=54). There were no dropouts or withdrawals throughout the study period.

drawing students' attention and piquing their interest in the topic. By connecting theoretical knowledge with its practical application, the case served as a catalyst for student engagement with the learning material.[7] ②Objective: In the Objective (O) phase, the instructor clearly outlined the learning objectives and key points. This provided students with a structured framework, guiding their focus toward the most relevant aspects of ECMO training.[8] ③Preassessment: In the Preassessment phase, a brief test was administered to evaluate students' existing knowledge and identify specific gaps in understanding. This assessment provided valuable insights into areas requiring further attention, allowing for a more tailored and focused approach to subsequent learning.[9] ④Participatory Learning: In the Participatory Learning phase, students were encouraged to independently review ECMO-related theoretical concepts.[7] Engaging discussions connected the principles of mechanical ventilation to ECMO use, while students were guided through various clinical scenarios. This approach allowed them to explore how different disease conditions impact ECMO parameter adjustments, thereby enhancing their understanding of the practical application of ECMO in critical care.[10] ⑤Postassessment: In the Postassessment phase, following the participatory learning session, students underwent a simulation-based evaluation. During this assessment, they performed hands-on ECMO procedures, which reinforced their theoretical knowledge and practical skills, ensuring a deeper understanding of the techniques involved.[11] ⑥Summary: In the Summary phase, the instructor consolidated key concepts using tools such as knowledge trees, framework diagrams, and mind maps. These methods encouraged students to engage in post-class learning, further reinforcing their understanding of the material.[12]

The multidisciplinary team (MDT) for ECMO training consisted of ICU physicians, cardiac surgeons, ICU nurses, respiratory therapists, cardiac ultrasound physicians, pharmacists, and nutritionists. Each discipline provided specialized instruction on their respective areas, such as ECMO cannulation, patient monitoring, respiratory management, and pharmacotherapy. Regular MDT case discussions offered interns a comprehensive and integrated learning approach, facilitating a deeper understanding of ECMO's clinical application and interdisciplinary management.

## Observational Indicators

The total score was comprised of five sections: theoretical knowledge, practical skills, case analysis, response ability, and collaboration ability. The theoretical knowledge section evaluated 16 key ECMO concepts, with scores assigned according to the level of understanding: 6.25 points for full comprehension, 3 points for partial understanding, and 0 points for no understanding. The theoretical knowledge score, initially out of 100 points, was scaled to 20 points for the total score. Practical skills were evaluated by participants' ability to accurately connect ECMO circuits, ensuring both safety and functionality, as well as their proficiency in adjusting ECMO parameters based on the patient's clinical condition. The case analysis section involved a clinical scenario to test participants' analytical skills and clinical decision-making. Response ability was assessed through simulated emergency situations, including scenarios like bleeding, tubing malfunctions, airway issues, infections, circulatory complications, and electrolyte imbalances, to measure how effectively and promptly participants could manage these crises. Finally, collaboration ability was evaluated based on participants' teamwork and their ability to collaborate efficiently within a multidisciplinary team, reflecting the importance of effective communication and coordination in ECMO management.

After the completion of the teaching, a survey questionnaire was administered to the students. A comprehensive search was conducted in both domestic and international clinical education databases to identify existing teaching questionnaires and to develop a new instrument tailored to this course. The databases consulted included China National Knowledge Infrastructure (CNKI), Wanfang Medical Network, Web of Science, PubMed, Cochrane, and PEDro. The search terms used were: "Teaching", "BOPPPS", "MDT", and "questionnaire", with a publication date range limited to the past five years. Based on the retrieved literature and the specific characteristics of this course, a new questionnaire was developed consisting of 13 items, covering five dimensions. The developed questionnaire was then subjected to reliability and validity analyses. The reliability of the questionnaire was evaluated by randomly selecting 30 students from the recruited participants. After watching a highlight video, the students were asked to complete the questionnaire. After a two-week interval, they were asked to fill out the same questionnaire again. The test-retest reliability was calculated by analyzing the intraclass correlation coefficient (ICC) of each item and the overall questionnaire score. Internal consistency was assessed using Cronbach's α coefficient. A Cronbach's α coefficient >0.8 indicates high reliability, between 0.6 and 0.8 indicates good reliability, and between 0.5 and 0.6 indicates acceptable reliability. For construct validity, another group of 30 students was randomly selected to watch the highlight video and complete the questionnaire. Principal component analysis was performed to assess whether the results of the questionnaire aligned with the theoretical structure. The factor loading and correlation among items were analyzed to determine whether the scale represented the theoretical dimensions intended. Content validity was assessed by consulting with two groups of six experts each, consisting of clinical educators and clinicians. The experts were asked to evaluate the relevance of each item and research question on the questionnaire, using a scale of "not relevant", "weakly relevant", "moderately relevant", and "highly relevant". The content validity index (I-CVI) for each item and the scale-level content validity index (S-CVI) were calculated. An I-CVI value ≥0.78 and an S-CVI value ≥0.90 were considered indicative of good content validity.

## Statistical Methods

In this study, statistical analyses were performed using SPSS 22.0 software (IBM, New York, United States). Continuous variables were expressed as mean ± standard deviation (SD) for normally distributed data or median (interquartile range, IQR) for non-normally distributed data. Categorical variables were presented as numbers and percentages. Comparisons between groups for continuous variables were conducted using the Student's *t*-test for normally distributed data with homogeneity of variance or the Mann–Whitney *U*-test for non-normally distributed data. Categorical variables were analyzed using the Chi-square test or Fisher's exact test, as appropriate. Cronbach's α coefficient and test-retest reliability were calculated. The structural validity was assessed by calculating the Kaiser-Meyer-Olkin (KMO) value and Bartlett's test of sphericity. Content validity was analyzed by calculating the item-level content validity index (I-CVI) and scale-level content validity index (S-CVI).

# Results

## Comparison of Baseline Characteristics Between the Two Groups

The baseline characteristics of age, gender, education level, work experience, and major between the two groups of interns showed no statistically significant differences. Master's and doctoral majors included critical care medicine, cardiology, and cardiovascular surgery, while bachelor's majors were all in clinical medicine(Table 1). The educational and professional backgrounds of the two groups are shown in Figure 2.

## Comparison of Theoretical Knowledge Scores Between the Two Groups

After the completion of the training, a theoretical knowledge test was conducted for both groups of students. The theoretical knowledge test had a maximum score of 100 points, which accounted for 20% of the total score. Except for the scores related to procedural steps, thrombosis, bleeding and hemolysis complications, and pipeline abnormalities, where no significant differences were observed between the two groups, the scores of the experimental group were significantly higher than those of the control group in the other 13 scoring points. Additionally, the overall scores of the experimental group were significantly higher than those of the control group ($P < 0.05$)(Table 2).

## Comparison of Total Scores Between the Two Groups of Students

After the completion of the training, a total score assessment was conducted for both groups of students. Each section had a maximum score of 100 points, and the total score was calculated by multiplying the section score by 20%. The scores of the experimental group in theoretical knowledge, case analysis, collaboration ability, as well as the overall total score, were significantly higher than those of the control group ($P < 0.05$)(Table 3). The component scores within the total score are displayed in Figure 3.

## Reliability of the Scale

The Cronbach's α coefficients and test-retest reliability for each dimension of the questionnaire are shown in Table 4. The reliability analysis indicated high internal consistency and stability for all dimensions of the scale. The Cronbach's α coefficients ranged from 0.757 to 0.905, with the Feedback & Assessment dimension showing the highest consistency (0.905). The test-retest reliability values ranged from 0.847 to 0.916, indicating good temporal stability across all dimensions. Specifically, the Learning Outcomes dimension exhibited the highest test-retest reliability (0.910), suggesting that the scale reliably measures this aspect over time. Overall, the results support the robustness of the scale in assessing the various dimensions of the educational process.

**Table 1** Comparison of Baseline Data Between the Two Groups of Students

| | Control Group (n=54) | Experimental Group (n=54) | $\chi^2$ / t / Fisher's Exact Test Value | *P* value |
|---|---|---|---|---|
| Age | 26.43±6.45 | 24.52±5.37 | 1.672 | 0.097 |
| Gender (Male) | 37 | 34 | 0.370 | 0.543 |
| Educational Background | | | | |
| Doctorate | 12 | 15 | 0.444 | 0.505 |
| Master | 21 | 17 | 0.650 | 0.420 |
| Bachelor | 21 | 22 | 0.039 | 0.844 |
| Work Experience | 9 | 6 | 0.697 | 0.404 |
| Major | | | | |
| Critical Care Medicine | 19 | 15 | 0.687 | 0.407 |
| Cardiovascular Medicine | 11 | 10 | 0.059 | 0.808 |
| Cardiovascular Surgery | 3 | 7 | 0.395 | 0.320 |
| Clinical Medicine | 21 | 22 | 0.039 | 0.844 |

**Note**: The statistical methods used are as follows: $\chi^2$ values were used for categorical variables with expected counts ≥5; Fisher's exact test values were used for categorical variables with expected counts <5; T values were used for continuous variables with normal distribution and homogeneity of variance.

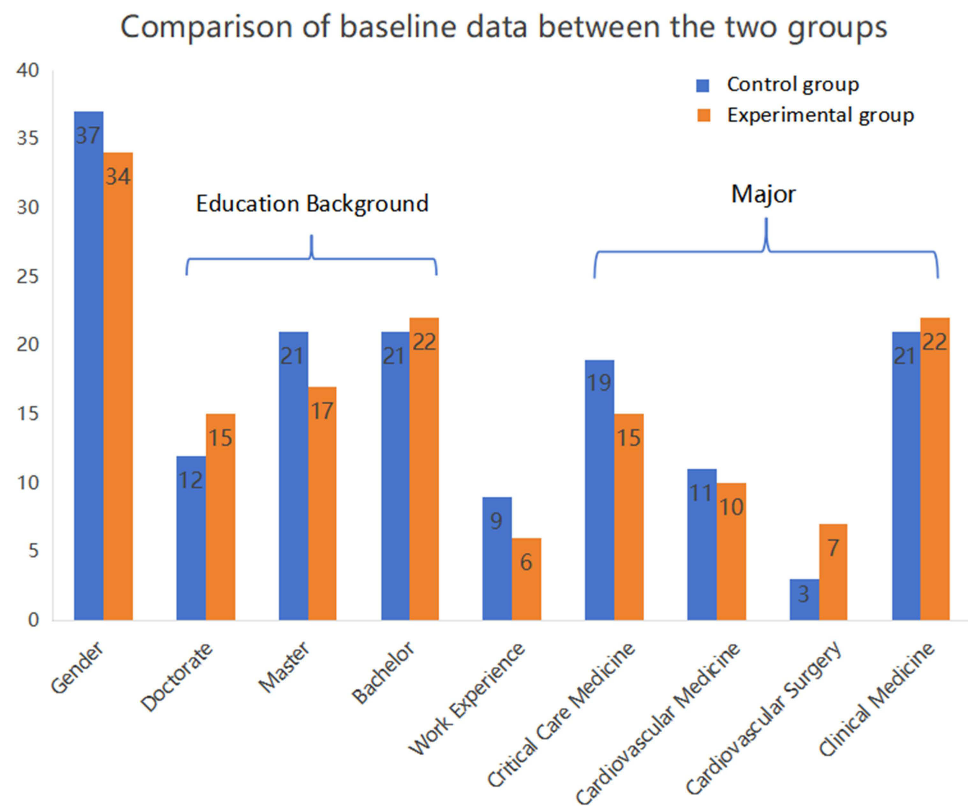



**Figure 2** Comparison of baseline data between the experimental group and the control group. There were no significant differences in gender, educational background, or major between the two groups.

## Validity Analysis

### Structural Validity

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.953, and the Bartlett's test of sphericity yielded a chi-square value of 7483.56 ($p < 0.01$), indicating that the data were suitable for factor analysis. A KMO value greater than 0.7 suggests good validity, while a value below 0.5 indicates poor validity of the questionnaire.

### Clarity and Content Validity

The clarity scores for each item were consistently high, with an average score ranging from 9.3 ±0.5 to 9.8±0.4. The Item Content Validity Index (I-CVI) for individual items ranged from 0.921 to 0.969, indicating strong item-level content validity. The Scale Content Validity Index (S-CVI/Ave) was 0.945, which is above the acceptable threshold of 0.9, demonstrating that the overall scale content validity was high. Items with I-CVI values greater than 0.78 and S-CVI values greater than 0.9 indicate that the research tool possesses good content validity(Table 5).

**Table 2** Comparison of Theoretical Knowledge Scores Between the Two Groups

| | Control Group (n=54) | Experimental Group (n=54) | t Value | P value |
|---|---|---|---|---|
| ECMO Basic Knowledge | – | – | | |
| Principles and Mechanisms | 4.40±0.35 | 4.63±0.39 | −3.112 | 0.002 |
| Indications and Contraindications | 4.37±0.29 | 4.61±0.47 | −3.203 | 0.002 |
| Equipment and Components | 4.55±0.38 | 4.84±0.49 | −3.427 | 0.001 |
| Operational Steps | 4.63±0.41 | 4.58±0.42 | 0.680 | 0.498 |

(*Continued*)

**Table 2** (Continued).

| | Control Group (n=54) | Experimental Group (n=54) | t Value | P value |
|---|---|---|---|---|
| ECMO Monitoring | – | | | |
| Hemodynamic Monitoring | 4.46±0.31 | 4.73±0.37 | −4.128 | 0.000 |
| Oxygenation Index Monitoring | 4.46±0.31 | 4.67±0.42 | −2.976 | 0.004 |
| Coagulation Function Monitoring | 4.57±0.40 | 4.76±0.46 | −2.221 | 0.028 |
| Infection Monitoring | 4.65±0.45 | 5.02±0.50 | −4.075 | 0.000 |
| Respiratory Function Monitoring | 4.43±0.28 | 4.80±0.48 | −4.844 | 0.000 |
| Metabolic Monitoring | 4.46±0.33 | 4.77±0.50 | −3.928 | 0.000 |
| ECMO Complications Management | – | – | | |
| Thrombosis, Bleeding, and Hemolysis | 4.57±0.39 | 4.56±0.45 | 0.157 | 0.876 |
| Infection | 4.56±0.34 | 5.09±0.52 | −6.353 | 0.000 |
| Pipeline Abnormalities | 4.67±0.40 | 4.73±0.51 | −0.596 | 0.553 |
| Air Embolism | 4.54±0.37 | 4.87±0.53 | −3.691 | 0.000 |
| Oxygenator Dysfunction | 4.46±0.28 | 4.84±0.53 | −4.625 | 0.000 |
| Equipment Malfunction | 4.45±0.29 | 5.01±0.50 | −7.160 | 0.000 |
| Total Score | 72.23±1.29 | 76.50±2.66 | −10.594 | 0.000 |

**Table 3** Comparison of Total Scores Between the Two Groups

| Group | Theoretical Knowledge | Practical Skills | Case Analysis | Response ability | Collaboration ability | Total Score |
|---|---|---|---|---|---|---|
| Control Group (n=54) | 14.49±0.28 | 15.04±1.93 | 15.09±1.86 | 16.59±1.85 | 14.06±2.08 | 75.26±4.34 |
| Experimental group (n=54) | 15.36±0.62 | 15.89±2.81 | 16.17±2.34 | 17.04±2.10 | 15.74±2.52 | 80.19±4.79 |
| T value | −0.9445 | −1.834 | −2.645 | −1.167 | −3.792 | −5.601 |
| P value | 0.000 | 0.069 | 0.009 | 0.246 | 0.000 | 0.000 |

## Student Satisfaction Survey Comparison Between the Two Groups

After the training, a satisfaction survey was conducted across five dimensions. A total of 108 questionnaires were distributed, and 102 were collected, with 50 from the control group and 52 from the experimental group. The satisfaction rate for the traditional teaching method was 75.42%, while the satisfaction rate for the BOPPPS-MDT combined teaching method was 92.17%. There was a statistically significant difference in satisfaction between the two groups ($\chi^2$=10.331, P=0.001). The BOPPPS-MDT combined teaching method significantly outperformed the traditional method in enhancing participation and interactivity, increasing feedback and evaluation, boosting interest in learning, improving teamwork skills, and enhancing learning outcomes(Table 6).

# Discussion

ECMO is widely used in ICUs to treat heart and lung failure caused by various conditions such as ARDS, cardiogenic shock, and refractory arrhythmias.[13–15] As a highly complex and high-risk life support system, ECMO plays a vital role in saving critically ill patients. Beyond being a technical procedure, ECMO training is crucial for improving clinical decision-making skills and fostering safety awareness among interns.[2] Mastering ECMO operation and related knowledge is an essential step in enhancing clinical capabilities and promoting teamwork in healthcare.[16]

The BOPPPS-MDT model offers a comprehensive and dynamic approach to medical education, with the BOPPPS model consisting of several stages: bridge-in, objective, pre-assessment, participatory learning, post-assessment, and summary.[4,5,17–19] When integrated with MDT (multidisciplinary teamwork), this approach enhances both theoretical

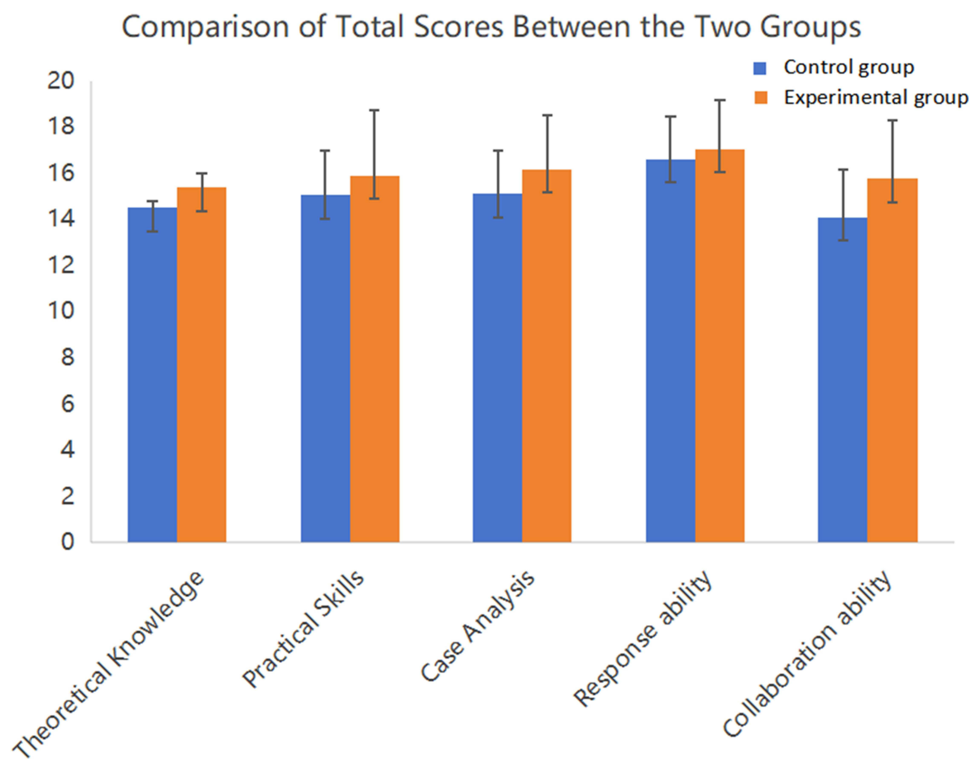



**Figure 3** Comparison of total scores between the experimental group and the control group. The experimental group achieved significantly higher scores in theoretical knowledge, case analysis, collaboration ability, and overall total score compared to the control group (P < 0.05). There were no significant differences in practical skills and response ability between the two groups.

knowledge and practical skills, encouraging active participation and fostering a deeper understanding of ECMO-related procedures. In support of our findings, previous research has also demonstrated the advantages of the BOPPPS teaching model in medical education.[20] A comprehensive meta-analysis by Ma et al[21] evaluated the effectiveness of the BOPPPS strategy compared to traditional lecture-based learning (LBL) in Chinese medical courses. The study reviewed 41 studies, including 34 randomized controlled trials (RCTs) and 7 cohort studies, involving a total of 5042 medical students. The meta-analysis found that the BOPPPS strategy significantly improved skill scores (SMD: 1.15, 95% CI: 1.00–1.30, P < 0.00001), knowledge examination scores (SMD: 1.56, 95% CI: 1.24–1.89, P < 0.00001), comprehensive ability scores (SMD: 1.22, 95% CI: 0.85–1.59; P < 0.00001), and teaching satisfaction (OR: 3.64; 95% CI: 2.97–4.46; P < 0.0001) compared to the LBL model. These findings reinforce the notion that the BOPPPS strategy is more effective in enhancing both theoretical understanding and practical skills among medical students compared to traditional methods.

Heling Wen et al[9] assessed the impact of combining the BOPPPS model with case-based learning (CBL) on nursing students' ECG interpretation skills. Nursing students were divided into two groups: one using BOPPPS-CBL and the other using traditional lecture-based learning (LBL). The results showed that the BOPPPS-CBL model significantly improved ECG interpretation skills and student attitudes toward learning, suggesting it as a more effective alternative to

**Table 4** Reliability Coefficients for the Overall Scale and Each Dimension

| Dimension | Number of Items | Cronbach's α Coefficient | Test-Retest Reliability |
|---|---|---|---|
| Participation & Interaction | 2 | 0.876 | 0.860 |
| Feedback & Assessment | 2 | 0.905 | 0.916 |
| Increased Interest | 5 | 0.863 | 0.847 |
| Teamwork | 2 | 0.757 | 0.882 |
| Learning Outcomes | 2 | 0.890 | 0.910 |

**Table 5** Clarity and Content Validity Analysis

| Item | Clarity Score | I-CVI (Item Content Validity Index) |
|---|---|---|
| 1 | 9.8±0.4 | 0.943 |
| 2 | 9.5±0.7 | 0.954 |
| 3 | 9.6±0.5 | 0.969 |
| 4 | 9.4±0.9 | 0.935 |
| 5 | 9.7±0.5 | 0.941 |
| 6 | 9.5±1.0 | 0.968 |
| 7 | 9.4±0.7 | 0.937 |
| 8 | 9.5±1.0 | 0.948 |
| 9 | 9.6±0.7 | 0.939 |
| 10 | 9.4±0.9 | 0.958 |
| 11 | 9.3±0.5 | 0.944 |
| 12 | 9.7±0.8 | 0.953 |
| S-CVI/Ave | | 0.948 |

**Table 6** Comparison of Satisfaction Surveys Between the Two Groups of Students

| Dimension | Item | Control Group | | Experimental Group | | χ2 Value | P value |
|---|---|---|---|---|---|---|---|
| | | Yes | No | Yes | No | | |
| Participation & Interaction | Increased participation | 15 | 35 | 36 | 16 | 15.692 | 0.000 |
| | Increased interaction | 13 | 37 | 35 | 17 | 17.458 | 0.000 |
| Feedback & Assessment | Real-time feedback mechanism | 18 | 32 | 40 | 12 | 17.403 | 0.000 |
| | Diverse assessment mechanisms | 18 | 32 | 31 | 21 | 5.695 | 0.017 |
| Increased Interest | Improved learning interest | 23 | 27 | 37 | 15 | 6.659 | 0.010 |
| | Increased course content attractiveness | 16 | 34 | 29 | 23 | 5.841 | 0.016 |
| | Enhanced learning diversity | 15 | 35 | 33 | 19 | 11.456 | 0.001 |
| | Increased learning personalization | 17 | 33 | 30 | 22 | 5.759 | 0.016 |
| | Enhanced learning atmosphere | 13 | 37 | 35 | 17 | 17.458 | 0.000 |
| Teamwork | Facilitated collective progress | 21 | 29 | 41 | 11 | 14.518 | 0.000 |
| | Benefited from each other's strengths | 12 | 38 | 36 | 16 | 20.932 | 0.000 |
| Learning Outcomes | Improved learning outcomes | 26 | 24 | 37 | 15 | 3.960 | 0.047 |
| | Increased learning efficiency | 24 | 26 | 39 | 13 | 7.869 | 0.005 |

traditional methods. Our findings are similar to those of previous studies, which also highlighted the effectiveness of combining the BOPPPS model with other methods in improving learning outcomes, and our study further demonstrates the advantages of the BOPPPS-MDT model in ECMO training compared to traditional teaching methods. The experimental group exhibited significant improvements in theoretical knowledge, with higher scores in ECMO basics, monitoring, and complication management. This reflects the BOPPPS-MDT model's capacity to effectively convey complex concepts through interactive and hands-on teaching. Additionally, the experimental group outperformed the control group in areas such as practical skills, case analysis, emergency response, and collaboration, highlighting the model's comprehensive impact on students' clinical competencies. Specifically, our results showed that the experimental group scored significantly higher across 13 of the 16 evaluation points, including key areas like ECMO operation, troubleshooting, and teamwork, which are critical for handling real-life scenarios. In the analysis of the total scores between the two groups, significant differences were observed in several dimensions. The experimental group scored significantly higher than the control group in theoretical knowledge (15.36±0.62 vs 14.49±0.28, $p < 0.01$), case analysis (16.17±2.34 vs 15.09±1.86, $p = 0.009$), and collaboration ability (15.74±2.52 vs 14.06±2.08, $p < 0.01$). However, no significant differences were found between the two groups in practical skills, response ability, and the overall total score (p>0.05). These findings suggest that the experimental teaching approach had a greater impact on the development of theoretical knowledge, case analysis, and collaboration skills compared to traditional methods. The lack of significant difference in practical skills and response ability may indicate that these competencies require more focused or prolonged training to fully develop. Overall, the enhanced theoretical understanding and teamwork observed in the experimental group suggest the potential efficacy of the BOPPPS-MDT teaching model in fostering comprehensive ECMO training. Moreover, the satisfaction survey results further support the effectiveness of the BOPPPS-MDT model. With a satisfaction rate of 92.17% in the experimental group compared to 75.42% in the control group, it is evident that students found the new teaching approach more engaging and beneficial. The increased satisfaction likely stems from the model's emphasis on interaction, feedback, and collaborative learning, which heightened students' involvement and motivation. Feedback from students also highlighted the benefits of real-time evaluations, which provided insights into their progress and areas for improvement. Additionally, the team-based learning environment fostered by the MDT component encouraged collaboration and communication, further enhancing their learning experience.

In conclusion, our study shows that the BOPPPS-MDT teaching model offers clear advantages in ECMO training, significantly improving students'theoretical knowledge, practical skills, emergency response capabilities, and collaboration abilities. The model also received higher satisfaction rates from students, reflecting its success in promoting interactive and comprehensive learning. These results suggest that the BOPPPS-MDT model has great potential for broader application in medical education, particularly in complex and high-stakes areas like ECMO training. By emphasizing practical skills, active participation, and team-based learning, this model could help address some of the limitations of traditional teaching methods and enhance the overall quality of medical training.

While these findings are encouraging, it is important to acknowledge the limitations of the study to provide a balanced perspective and guide future research efforts. This study has several limitations. First, it was conducted in a single-center setting, which may limit the generalizability of the findings to other institutions with different teaching environments or practices. Second, although we employed rigorous evaluation methods, the relatively small sample size may have affected the statistical power and generalizability of our results. Third, the follow-up period was short, and as a result, the long-term impact of the teaching approach on clinical practice and patient outcomes remains unknown. Fourth, while we aimed to minimize bias, subjective factors such as the teaching styles of instructors and individual differences among students may have influenced the study outcomes. Lastly, certain external factors, including variations in clinical cases and availability of simulation resources, may have also contributed to the variability in results. Further multi-center studies with larger sample sizes and longer follow-up periods are needed to validate our findings and provide more comprehensive insights into the effectiveness of this teaching approach.

## Abbreviations

BOPPPS-MDT, Bridge-in, Objectives, Pre-assessment, Participatory Learning, Post-assessment, and Summary model integrated with Multidisciplinary Team; ECMO, Extracorporeal membrane oxygenation; ICU, Intensive Care Unit; ARDS, Acute respiratory distress syndrome; MDT, Multidisciplinary team; RCT, Registered randomized controlled trial; CNKI, China National Knowledge Infrastructure; PubMed, Public Medicine; PEDro, Physiotherapy Evidence Database; ICC, Intraclass correlation coefficient; I-CVI, Item Content Validity Index; S-CVI, Scale Content Validity Index; SPSS, Statistical Package for the Social Sciences; SD, mean ± standard deviation; IQR, Interquartile range; KMO, Kaiser-Meyer-Olkin; LBL, lecture-based learning; CBL, case-based learning.

## Data Sharing Statement

The datasets generated 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 Wuhan NO.6 hospital(Approval No.[20220305]. All participants, including students involved in the study, were informed about the purpose of the research, and written informed consent was obtained prior to their participation. The participants were assured of their right to withdraw from the study at any time without any repercussions.

## Consent to Participate Declaration

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

## Consent for Publication

The authors confirm that there are no identifiable individuals involved in this study and that consent for publication is not applicable. All data presented in this manuscript is anonymized, and the study adheres to ethical guidelines for publication.

## Author Contributions

All authors made a significant contribution to the work reported, whether in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work. Specifically, Wenwen Tang contributed to the conception and design of the study; Wenjun Zhou wrote the manuscript; Langjing Huang performed the experiments, collected, and analyzed the data.

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## Disclosure

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