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RESEARCH

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Effectiveness of scaffolded case-based learning in anesthesiology residency training: a randomized controlled trial

LongYuan Zhou[1*], Chang Cai[1], RuiLan Wu[1] and Yong Qi[1*]

Abstract

Background Medical residents often struggle with complex clinical scenarios that require sophisticated decision-making skills. While case-based discussion (CBD) is widely used in medical education, its effectiveness can be limited by insufficient guidance and structured support. Scaffolding teaching, which provides graduated assistance aligned with learners' development, may address these limitations. However, evidence from randomized controlled trials evaluating the integration of scaffolding with CBD in residency training remains limited. This study aims to compare an integrated scaffolded case-based learning approach with traditional lecture-based teaching that utilizes the same clinical case materials in enhancing residents' clinical reasoning, self-directed learning, and knowledge acquisition in anesthesiology training.

Methods This prospective randomized controlled trial encompassed 12 anesthesiology residents, systematically randomized into an experimental cohort (receiving scaffolding teaching integrated with case-based discussion) and a control cohort (receiving traditional lecture-based instruction utilizing the same clinical case). The intervention consisted of a structured 4-week curriculum focusing on HOCM anesthesia management, delivered through weekly instructional sessions. The investigation utilized validated assessment instruments to measure primary outcomes, including clinical reasoning proficiency and self-directed learning capacity, at three time points: baseline, post-intervention (Week 4), and follow-up (Week 8). Secondary outcome measures encompassed teaching satisfaction indices and knowledge retention metrics. Statistical analysis employed t-tests and Mann-Whitney U tests for comparative assessment.

Results Post-intervention evaluation at Week 4 revealed statistically significant superiority in the experimental cohort across multiple parameters: clinical reasoning proficiency (83.58 ± 3.28 versus 74.17 ± 4.55, $p = 0.002$), self-directed learning capacity (79.92 ± 2.56 versus 63.33 ± 3.52, $p < 0.001$), and teaching satisfaction indices (100.00 ± 0.00 versus 73.00 ± 5.02, $p < 0.001$). Follow-up assessment at Week 8 demonstrated sustained enhancement in the experimental group, maintaining significant advantages in clinical reasoning proficiency (89.08 ± 5.93 versus 68.17 ± 2.70, $p < 0.001$),

*Correspondence:
LongYuan Zhou
396919647@qq.com
Yong Qi
qiyong1974@163.com
Full list of author information is available at the end of the article

self-directed learning capacity (87.83 ± 2.56 versus 71.58 ± 3.50, $p < 0.001$), and knowledge retention (98.33 ± 2.58 versus 95.00 ± 0.00, $p = 0.010$).

Conclusion This investigation demonstrates that an integrated scaffolding-supported case-based learning approach offers significant advantages over traditional lecture-based teaching that incorporates the same clinical case. The integrated approach significantly enhances clinical reasoning capabilities, self-directed learning competencies, and knowledge acquisition in complex clinical scenarios compared to the lecture-based approach. These findings establish a robust empirical foundation for the optimization of residency training methodologies, particularly within high-complexity clinical domains such as HOCM anesthesia management. The sustained improvements observed at follow-up further validate the long-term effectiveness of this integrated pedagogical approach.

Clinical trial registration Not applicable. This study is an educational research project evaluating teaching methodologies through simulated training and does not involve health-related interventions or patient outcomes.

Keywords Scaffolding teaching methodology, Case-based learning, Clinical reasoning proficiency, Self-directed learning competency, Knowledge acquisition and retention, Medical education innovation, Residency training, Anesthesia education, Cardiomyopathy management, Educational assessment methods

Introduction

Medical education faces the ongoing challenge of preparing healthcare professionals to manage increasingly complex clinical scenarios while meeting evolving healthcare demands. This challenge is particularly pronounced in residency training programs, where the development of advanced clinical reasoning capabilities is crucial. In China's current healthcare reform context, the optimization of residency training methodologies has become a critical focus for medical education research.

Case-based discussion (CBD) has emerged as a widely-adopted pedagogical approach in medical education, offering an interactive bridge between theoretical knowledge and clinical practice. Evidence supports its effectiveness in developing clinical reasoning skills and fostering critical thinking through contextualized learning and interprofessional collaboration [1, 2]. Studies have demonstrated CBD's success in promoting student engagement and active participation in collaborative learning environments [3, 4].

However, significant implementation challenges limit CBD's effectiveness in contemporary medical education. These include time and resource constraints in teaching hospitals [5], inconsistent educational quality due to insufficient instructor training, and variable student engagement patterns [6, 7]. Most critically, traditional CBD approaches often employ simplified scenarios that fail to capture the complexity of real clinical practice, particularly in high-risk cases where inadequate guidance may impede the development of clinical adaptability [8].

The scaffolding teaching model (STM), founded on constructivist learning theory, offers a potential solution through its structured support framework within learners' Zone of Proximal Development (ZPD). This approach employs strategic task decomposition and graduated withdrawal of support, fostering the development of advanced cognitive capabilities through experiential learning [9–11]. While promising, empirical validation of STM's effectiveness in medical education, particularly through randomized controlled trials, remains limited [12].

This study addresses three key gaps in current medical education research:1.The need for evidence-based teaching methodologies that effectively handle complex clinical scenarios;2.The integration of structured support systems within case-based learning; 3. The development of reproducible frameworks for enhancing clinical reasoning capabilities.

Using hypertrophic obstructive cardiomyopathy (HOCM) anesthesia management as a model case, this study compares an integrated scaffolding-supported case-based learning approach with traditional lecture-based teaching that utilizes the same clinical case. Our primary focus is evaluating the differential impacts of these teaching methodologies on residents' development of clinical reasoning and self-directed learning capabilities, assessed through systematic competency measurements.

Methods

Study design and participants

This educational randomized controlled trial was conducted to evaluate teaching methodologies in anesthesiology residency training. As this study focused exclusively on educational outcomes through simulated training scenarios and did not involve any health-related interventions or patient care, clinical trial registration was not applicable. The investigation employed a double-blind controlled trial design, with protocol and procedures receiving prior approval from the Ethics Committee of Ningbo Medical Center Lihuili Hospital (Approval No.: KY2022PJ193). The study adhered rigorously to relevant guidelines and regulations, with all participants providing written informed consent prior to study commencement. The participant cohort comprised resident physicians enrolled in the standardized training program at Ningbo Medical Center Lihuili Hospital, encompassing both Xingning and Eastern campus locations. All participants had completed requisite educational prerequisites, including a five-year undergraduate medical curriculum and a one-year clinical internship rotation.

To ensure methodological rigor and baseline homogeneity, participants were systematically matched between groups using a 1:1 ratio based on key demographic and academic variables, including gender, age, training duration, and academic performance metrics. The study enrolled a total of 12 anesthesiology residents, with equal distribution between experimental and control groups ($n = 6$ per group). Each group included a balanced representation across training levels: two first-year, two second-year, and two third-year residents. Geographic stratification determined group allocation, with Xingning campus residents constituting the control group (traditional lecture-based instruction) and Eastern campus residents forming the experimental group (scaffolded teaching integrated with case-based discussion).

The educational intervention maintained identical course duration and scheduling parameters across both groups, with simultaneous delivery by independent teaching teams at respective campus locations. To ensure standardization of educational content, all instructors underwent comprehensive training regarding course content and learning objectives, establishing uniformity in topic coverage and temporal progression. In accordance with double-blind methodology, instructors implemented their assigned teaching protocols (scaffolded teaching with CBD or traditional lecture-based instruction) without knowledge of group designations. Similarly, participants remained unaware of methodological differences between groups. Both cohorts focused on an identical clinical case study: "Anesthetic Management of a Patient with Hypertrophic Obstructive Cardiomyopathy (HOCM)."

Eligibility criteria

Inclusion parameters

The study enrolled participants meeting comprehensive eligibility requirements. Qualified candidates were required to be actively enrolled resident physicians in the standardized anesthesiology training program at Ningbo Medical Center Lihuili Hospital. Participants must have completed between one and three years of training, including a minimum of one year's clinical rotation experience across multiple specialty departments. Essential prerequisites included demonstrated competency in medical English literature comprehension and the capacity for full course participation. Additionally, candidates were required to provide written informed consent and have no recent participation in concurrent teaching methodology studies.

Exclusion parameters

The investigation established strict exclusion criteria to maintain methodological integrity. Candidates were deemed ineligible if they lacked specific clinical rotation experience in anesthesiology or demonstrated inability to fulfill complete course attendance requirements. Prior exposure to scaffolded teaching methodologies during formal training constituted an automatic exclusion criterion. The protocol mandated exclusion for participants exhibiting attendance deficiencies exceeding two sessions or failing to complete all evaluation components. Furthermore, individuals displaying significant performance variations that might impede course completion were excluded from participation. The study protocol also specified automatic withdrawal for participants experiencing training interruptions due to health complications, familial obligations, or other uncontrollable circumstances that could compromise study integrity.

Clinical case design and implementation protocol

Patient clinical profile

The study protocol centered on a complex clinical case (Patient Admission No.: 200516XX) involving a 65-year-old female patient scheduled for laparoscopic radical resection of rectal cancer, with an anticipated surgical duration of six hours. The patient presented with a progressive cardiovascular symptom profile, characterized by a six-month history of chest tightness and dyspnea, with recent exacerbation manifesting as chest pain over the preceding 12 days. The patient's longitudinal medical history was significant for a 20-year course of hypertension, maintained under pharmacological management with amlodipine and atorvastatin, achieving adequate blood pressure control.

Laboratory and diagnostic findings

Preoperative hematological assessment revealed significant anemia, with hemoglobin concentration at 57 g/L and hematocrit at 19.6%, although biochemical and electrolyte profiles remained within normal parameters. Advanced cardiovascular imaging through coronary CT angiography identified mild stenotic changes in the left anterior descending artery. Comprehensive echocardiographic evaluation demonstrated significant cardiac architectural and functional alterations, including: Interventricular septal hypertrophy (13–15 mm); Left ventricular outflow tract turbulence with elevated hemodynamic gradients (peak: 67 mmHg; mean: 37 mmHg); Moderate pulmonary hypertension; Mild-to-moderate mitral regurgitation.Electrocardiographic examination revealed multiple cardiac conduction and perfusion abnormalities, characterized by sinus rhythm with atrial premature complexes, T-wave inversions, and anterolateral ST-segment depression.

Experimental group: integration of scaffolded teaching with case-based discussion

Pedagogical structure The educational intervention comprised four sequential weekly sessions, each extending 1.5 h, designed to progressively develop clinical competencies through structured support and guided discovery.

Week 1: foundational knowledge development and problem identification The initial session established core conceptual understanding through systematic case presentation and comprehensive analysis of clinical data. Educational content focused on the advanced pathophysiological mechanisms of HOCM, emphasizing left ventricular outflow tract obstruction dynamics, cardiac functional assessment protocols, and the clinical significance of systolic anterior motion (SAM). Participants engaged in detailed analysis of potential intraoperative complications, including myocardial ischemia risk factors, hemodynamic instability patterns, and volume management challenges. Through structured guidance, residents conducted systematic evaluations of echocardiographic findings and electrocardiographic alterations, analyzing their implications for anesthetic management strategies.

Week 2: strategic planning and evidence-based management The second session advanced to complex problem-solving through collaborative development of comprehensive anesthetic management protocols. Participants formulated evidence-based strategies encompassing preoperative optimization parameters, pharmacological agent selection criteria, and hemodynamic management protocols. This process was augmented by systematic literature review and instructor-guided refinement of proposed interventions.

Week 3: clinical simulation with scenario-based learning Session three implemented dynamic scenario-based learning through simulated clinical challenges, including management of acute intraoperative hypotension and complex ventricular arrhythmias. Through structured role-play exercises simulating interprofessional team dynamics, participants assumed various clinical roles to execute and optimize their management strategies within a controlled educational environment.

Week 4: critical analysis and performance evaluation The final session focused on analytical synthesis and performance evaluation. Participants presented detailed analyses of simulation outcomes and proposed optimization strategies. Instructor-led assessment provided comprehensive evaluation of strategy feasibility and effectiveness, reinforcing critical knowledge elements through structured feedback mechanisms.

Control group: traditional lecture-based teaching with case illustration

Structured educational framework The control group participated in a four-week educational program, with weekly sessions of 1.5 h duration, following established lecture-based teaching methodologies. The teaching sessions utilized the same clinical case of anesthetic management for hypertrophic obstructive cardiomyopathy (HOCM) as the experimental group, but implemented through a fundamentally different pedagogical approach.

Unlike the experimental group, which employed an active case-based discussion methodology with scaffolding support, the control group received traditional instructor-led lectures that incorporated the case as illustrative material. This approach was supplemented by interactive question-and-answer sessions but did not include the structured small-group discussions, peer-to-peer interactive learning, or scaffolding elements that characterized the experimental intervention.

This design allows for comparison between lecture-based teaching with case illustration and an integrated scaffolding-supported case-based approach, rather than isolating the specific impact of scaffolding within case-based learning.

Week 1: fundamental knowledge Dissemination The initial session provided comprehensive didactic instruction on foundational concepts, beginning with detailed case presentation. The lecture encompassed extensive coverage of HOCM pathophysiology, with particular emphasis on complex perioperative risk factors. Instructors delivered systematic explanations of disease mechanisms and their clinical implications through traditional pedagogical approaches.

Week 2: clinical management principles The second session focused on systematic presentation of anesthetic management strategies. Through structured lectures, instructors provided detailed exposition of established protocols and evidence-based approaches to perioperative care. The presentation followed a methodical progression through each aspect of patient management, from preoperative assessment to postoperative considerations.

Week 3: applied case analysis Week three centered on instructor-led demonstration of comprehensive anesthetic management processes. Through detailed case analysis, participants observed the practical application of theoretical principles to clinical scenarios. The session emphasized the integration of knowledge components through systematic review of management decisions and outcomes.

Week 4: knowledge synthesis and reinforcement The final session concentrated on consolidating essential concepts through comprehensive review. Instructors facilitated interactive question-and-answer sessions designed to reinforce critical knowledge points and address specific areas requiring clarification. This culminating session provided systematic coverage of key learning objectives while allowing for structured knowledge assessment.

Assessment parameters and evaluation metrics

Primary outcome measures

Clinical reasoning assessment The evaluation of clinical reasoning capabilities employed the Direct Observation of Procedural Skills (DOPS) framework [13]. While maintaining the core DOPS methodology, we adapted and validated the framework specifically for anesthesiology residency training. The modified instrument incorporates five distinct assessment dimensions: problem identification (20% weighting), analytical reasoning processes (25% weighting), clinical decision-making capabilities (25% weighting), implementation proficiency (20% weighting), and feedback integration (10% weighting). This adaptation underwent rigorous content validation by a panel of five expert anesthesiologists and medical educators to ensure its reliability and applicability in our educational context. The assessment yielded a composite score with a maximum of 100 points.

Self-directed learning evaluation Self-directed learning proficiency was quantified using an adapted version of the validated Self-Directed Learning Readiness Scale (SDLRS) [14].Our modified instrument, validated through expert panel review, evaluated four critical domains of learning autonomy: learning motivation (25% weighting), strategic learning plan development (25% weighting), effective resource utilization (20% weighting), and reflective learning practices (30% weighting). The assessment utilized a 5-point Likert scale framework, generating a comprehensive score out of 100 points.

Secondary outcome measures

Teaching satisfaction The teaching satisfaction evaluation protocol was developed based on established educational assessment principles [15] and underwent thorough validation by our expert panel. This structured assessment framework utilized a 5-point Likert scale to evaluate three primary dimensions: instructional content clarity (40% weighting), pedagogical method interactivity (30% weighting), and overall educational effectiveness (30% weighting). These components contributed to a total possible score of 100 points.

Knowledge acquisition assessment Cognitive mastery was evaluated through a comprehensive multiple-choice examination. The assessment instrument was structured to evaluate two primary components: clinical data interpretation proficiency (50 points) and core anesthetic management knowledge (50 points), culminating in a maximum achievable score of 100 points.

Assessment protocol and implementation timeline

Week 1: baseline assessment Prior to course commencement, a comprehensive baseline assessment of clinical reasoning competencies was administered utilizing the Direct Observation of Procedural Skills (DOPS) framework. This evaluation protocol encompassed three fundamental dimensions: problem identification, analytical reasoning, and decision-making capabilities. The assessment employed a validated weighted scoring methodology, with a maximum attainable score of 70 points. Concurrent evaluation of self-directed learning competency was conducted through the implementation of the Self-Directed Learning Readiness Scale (SDLRS), which yielded a potential maximum score of 100 points. Furthermore, knowledge acquisition was quantitatively measured through a standardized examination protocol, similarly structured with a maximum obtainable score of 100 points.

Week 4: post-course evaluation The post-course evaluation employed a simulation-based assessment methodology focusing on acute hemodynamic changes during anesthesia management. The clinical scenarios were designed to assess residents' responses to sudden hypotension and tachycardia in the perioperative setting. The assessment metrics incorporated four key components: clinical reasoning competency evaluation using the Direct Observation of Procedural Skills (DOPS) framework, self-directed learning capability measurement via the Self-Directed Learning Readiness Scale (SDLRS), knowledge acquisition assessment through standardized testing, and teaching satisfaction analysis. Each assessment component was structured with a maximum attainable score of 100 points to ensure standardized evaluation across all domains.

Week 8: follow-up assessment The long-term efficacy evaluation implemented a simulation-based assessment protocol centered on postoperative hemodynamic management, with particular emphasis on addressing hypotension in the recovery period. The assessment framework maintained methodological consistency with previous evaluations, incorporating three standardized components: clinical reasoning evaluation through the Direct Observation of Procedural Skills (DOPS) framework, self-directed learning competency assessment via the Self-Directed Learning Readiness Scale (SDLRS), and knowledge acquisition measurement. Each assessment component retained a maximum attainable score of 100 points to ensure standardized performance evaluation across all domains.

Statistical analysis protocol

Analytical Framework Statistical analyses were conducted using SPSS version 21.0 statistical software. The analytical approach encompassed comprehensive examination of baseline characteristics, longitudinal outcome measures, and between-group comparisons across multiple time points.

Statistical methodology

Baseline demographic and clinical characteristics were analyzed using descriptive statistics. Between-group comparisons employed parametric (independent t-tests) or non-parametric (Mann-Whitney U test) analyses based on data distribution characteristics. Longitudinal outcome assessment across three time points (baseline, Week 4, and Week 8) utilized identical statistical methodologies. Analysis of teaching satisfaction metrics, collected at Week 4, implemented similar statistical approaches based on data distribution patterns. Statistical significance was established at a two-sided P value threshold of 0.05.

Data quality assurance

To maintain robust data integrity, the study implemented a dual-entry verification system, with independent data entry performed by two separate investigators. Regular auditing procedures were established to ensure continued data accuracy and completeness throughout the analysis phase.

Study power considerations

Given the exploratory nature of this investigation with its defined sample size ($n = 12$), the analytical focus emphasized preliminary evidence generation. The results were interpreted within the context of providing foundational data to inform the design and implementation of subsequent larger-scale investigations.

Results

Baseline group comparability

Baseline assessments revealed no significant differences between the experimental and control groups across all measured parameters. Clinical reasoning ability scores were comparable between the experimental (32.00 ± 3.49) and control groups (30.67 ± 3.33, $P = 0.514$), with similar patterns observed across all subdomains including problem identification (10.33 ± 1.97 vs. 9.00 ± 2.10, $P = 0.282$), analysis and reasoning (8.33 ± 2.04 vs. 8.33 ± 3.03, $P = 1.000$), and decision making (13.33 ± 2.04 vs. 13.33 ± 2.04, $P = 1.000$). Self-directed learning assessment demonstrated equivalent capabilities between the experimental (51.50 ± 3.71) and control groups (50.25 ± 1.41, $P = 0.459$), including learning motivation, planning, resource utilization, and reflective learning components. Initial knowledge acquisition metrics also showed no significant differences between the experimental (49.17 ± 7.36) and control groups (52.50 ± 6.12, $P = 0.414$), establishing a homogeneous foundation for evaluating the intervention's effectiveness.See Table 1.

Post-intervention outcomes analysis at week 4

The comparative analysis at Week 4 revealed substantial differences in performance metrics between the experimental and control groups across multiple domains of assessment. Clinical reasoning ability scores

Table 1 Comparison of baseline characteristics between groups ($n = 6$, mean ± SD)

Outcome Measures	Experimental Group	Control Group	t-value	t-test *p*-value	Z-value	Mann-Whitney U test *p*-value
Clinical Reasoning Ability	32.00 ± 3.49	30.67 ± 3.33	0.677	0.514	-0.561	0.575
Problem Identification	10.33 ± 1.97	9.00 ± 2.10	1.136	0.282	-1.087	0.277
Analysis and Reasoning	8.33 ± 2.04	8.33 ± 3.03	0.000	1.000	0.000	1.000
Decision Making	13.33 ± 2.04	13.33 ± 2.04	0.000	1.000	0.000	1.000
Self-Directed Learning	51.50 ± 3.71	50.25 ± 1.41	0.771	0.459	-1.286	0.199
Learning Motivation	16.25 ± 1.37	15.00 ± 2.24	1.168	0.270	-1.038	0.299
Learning Planning	13.75 ± 2.09	14.58 ± 1.02	-0.877	0.401	-0.738	0.461
Resource Utilization	6.00 ± 1.79	5.67 ± 1.51	0.349	0.734	-0.341	0.733
Reflective Learning	15.50 ± 2.26	15.00 ± 0.00	0.542	0.599	-0.632	0.527
Knowledge Acquisition	49.17 ± 7.36	52.50 ± 6.12	-0.853	0.414	-0.832	0.406

Note: Clinical Reasoning Ability has a maximum score of 70 points (Problem Identification: 20 points, Analysis and Reasoning: 25 points, Decision Making: 25 points). Self-Directed Learning has a maximum score of 100 points (Learning Motivation: 25 points, Learning Planning: 25 points, Resource Utilization: 20 points, Reflective Learning: 30 points). Knowledge Acquisition has a maximum score of 100 points

Table 2 Comparison of assessment outcomes between groups at week 4 and week 8 ($n = 6$, mean ± SD)

Assessment Metrics	Experimental Group	Control Group	t-value	t-test *p*-value	Z-value	Mann-Whitney U test *p*-value
Week 4 Outcomes						
Clinical Reasoning Ability	83.58 ± 3.28	74.17 ± 4.55	4.116	0.002*	-2.892	0.004*
Problem Identification	18.33 ± 1.97	16.67 ± 1.03	1.838	0.096	-1.563	0.118
Analysis and Reasoning	21.25 ± 2.62	19.17 ± 1.29	1.746	0.111	-1.554	0.120
Decision Making	20.00 ± 1.58	18.33 ± 2.04	1.581	0.145	-1.441	0.150
Implementation	15.67 ± 1.51	11.67 ± 1.51	4.602	0.001*	-2.786	0.005*
Feedback Adoption	8.33 ± 0.82	8.33 ± 0.82	0.000	1.000	0.000	1.000
Self-Directed Learning	79.92 ± 2.56	63.33 ± 3.52	9.342	<0.001*	-32.898	0.004*
Learning Motivation	22.50 ± 2.24	22.08 ± 2.46	0.307	0.765	-0.341	0.733
Learning Planning	20.42 ± 1.02	19.58 ± 1.88	0.953	0.363	-0.957	0.338
Resource Utilization	12.00 ± 1.26	5.67 ± 1.51	7.889	<0.001*	-2.961	0.003*
Reflective Learning	25.00 ± 1.55	16.00 ± 1.55	10.062	<0.001*	-3.000	0.003*
Knowledge Acquisition	99.17 ± 2.04	96.67 ± 4.08	1.342	0.209	-1.251	0.211
Week 8 Outcomes						
Clinical Reasoning Ability	89.08 ± 5.93	68.17 ± 2.70	7.868	<0.001*	-2.903	0.004*
Problem Identification	18.33 ± 2.34	13.33 ± 1.63	4.294	0.002*	-2.622	0.009*
Analysis and Reasoning	21.67 ± 2.58	15.83 ± 1.29	4.950	0.001*	-2.812	0.005*
Decision Making	22.08 ± 3.32	15.00 ± 1.58	4.715	0.001*	-2.884	0.004*
Implementation	17.33 ± 1.63	14.67 ± 1.03	3.381	0.007*	-2.544	0.011*
Feedback Adoption	9.67 ± 0.82	9.33 ± 1.03	0.620	0.549	-0.638	0.523
Self-Directed Learning	87.83 ± 2.56	71.58 ± 3.50	9.178	<0.001*	-2.892	0.004*
Learning Motivation	21.67 ± 2.04	20.83 ± 2.04	0.707	0.496	-0.957	0.338
Learning Planning	22.50 ± 1.58	22.08 ± 1.02	0.542	0.599	-0.527	0.598
Resource Utilization	15.67 ± 1.51	5.67 ± 1.51	11.504	<0.001*	-2.934	0.003*
Reflective Learning	28.00 ± 1.55	23.00 ± 1.55	5.590	<0.001*	-3.000	0.003*
Knowledge Acquisition	98.33 ± 2.58	95.00 ± 0.00	3.162	0.010*	-2.345	0.019*

Note: Clinical Reasoning Ability was assessed through dynamic simulation scenarios at Weeks 4 and 8 (maximum score: 100 points; comprising Problem Identification: 20 points, Analysis and Reasoning: 25 points, Decision Making: 25 points, Implementation: 20 points, Feedback Adoption: 10 points). Self-Directed Learning has a maximum score of 100 points (Learning Motivation: 25 points, Learning Planning: 25 points, Resource Utilization: 20 points, Reflective Learning: 30 points). Knowledge Acquisition has a maximum score of 100 points. *Indicates statistical significance at $p < 0.05$

Table 3 Comparison of teaching satisfaction scores between groups at week 4 ($n = 6$, mean ± SD)

Teaching Satisfaction Components	Experimental Group	Control Group	t-value	t-test *p*-value	Z-value	Mann-Whitney U test *p*-value
Overall Teaching Satisfaction	100.00 ± 0.00	73.00 ± 5.02	13.175	<0.001*	-3.600	<0.001*
Content Clarity and Practicality	40.00 ± 0.00	40.00 ± 0.00	N/A	1.000	0.000	1.000
Teaching Method Interactivity and Engagement	30.00 ± 0.00	13.00 ± 2.45	16.996	<0.001*	-3.847	<0.001*
Overall Teaching Effectiveness	30.00 ± 0.00	20.00 ± 3.10	7.906	<0.001*	-3.135	0.002*

Note: Teaching satisfaction was evaluated using a 100-point scale comprising three domains: Content Clarity and Practicality (40 points), Teaching Method Interactivity and Engagement (30 points), and Overall Teaching Effectiveness (30 points). *Indicates statistical significance at $p < 0.05$

demonstrated significant differentiation, with the experimental group achieving a mean score of 83.58 ± 3.28 compared to 74.17 ± 4.55 in the control group ($P < 0.05$). This pattern of enhanced performance extended to self-directed learning ability, where the experimental group attained a mean score of 79.92 ± 2.56, markedly higher than the control group's 63.33 ± 3.52 ($P < 0.05$).See Table 2.

Knowledge acquisition assessment revealed a trend toward superior performance in the experimental group (99.17 ± 2.04) compared to the control group (96.67 ± 4.08), although this difference did not achieve statistical significance ($P = 0.209$).See Table 2.

Teaching satisfaction metrics demonstrated particularly striking differentiation, with the experimental group achieving maximum satisfaction scores (100.00 ± 0.00) compared to notably lower scores in the control group (73.00 ± 5.02, $P < 0.05$). The most pronounced disparities in satisfaction ratings were observed in dimensions related to teaching format interactivity and overall pedagogical engagement.See Table 3.

These findings suggest that the integration of scaffolded teaching with case-based discussion yielded substantial improvements in critical educational outcomes, particularly in domains requiring higher-order cognitive processing and active learning engagement. The consistent pattern of enhanced performance across multiple assessment domains supports the efficacy of this innovative pedagogical approach.

Follow-up assessment outcomes at week 8

The longitudinal analysis conducted at Week 8 revealed further enhancement and consolidation of the experimental group's performance advantages across all measured domains. The differentiation in outcomes became more pronounced compared to the Week 4 assessment, with statistical significance emerging in previously marginal comparisons.See Table 2.

Clinical reasoning ability demonstrated particularly notable improvement in the experimental group, which achieved a mean score of 89.08 ± 5.93, representing a substantial increase from Week 4 results. This performance significantly exceeded the control group's mean score of 68.17 ± 2.70 ($P < 0.05$), with the magnitude of difference expanding compared to the Week 4 assessment.See Table 2.

Self-directed learning ability similarly showed sustained enhancement in the experimental group, with participants achieving a mean score of 87.83 ± 2.56. This result maintained a statistically significant advantage over the control group's performance of 68.17 ± 2.70 ($P < 0.05$). The persistence and expansion of this performance gap suggests durable improvement in self-directed learning capabilities among participants exposed to the integrated teaching methodology.See Table 2.

The follow-up assessment also revealed emergence of statistical significance in knowledge acquisition metrics, which had previously shown only marginal differentiation at Week 4. This evolution in performance metrics suggests that the integrated teaching approach not only produces immediate improvements in learning outcomes but also facilitates sustained enhancement of clinical competencies over time.See Table 2.

Longitudinal analysis of performance dimensions

Clinical reasoning competency analysis

Detailed examination at Week 8 revealed the experimental group's consistent superiority across all clinical reasoning dimensions. The experimental cohort demonstrated significantly elevated performance in problem identification (18.33 ± 2.34), analysis and reasoning (21.67 ± 2.58), decision-making (22.08 ± 3.32), and implementation ability (17.33 ± 1.63). These metrics substantially exceeded the control group's corresponding scores of 13.33 ± 1.63, 15.83 ± 1.29, 15.00 ± 1.58, and 14.67 ± 1.03, respectively ($P < 0.05$).

The temporal analysis from Week 4 to Week 8 revealed distinct developmental patterns between groups. The experimental group exhibited progressive enhancement in higher-order cognitive domains—problem identification, analysis and reasoning, and decision-making—while maintaining steady improvement in implementation skills. Conversely, the control group's performance trajectory showed concerning patterns. Despite modest improvement in implementation ability from Week 4 (11.67 ± 1.51) to Week 8 (14.67 ± 1.03), these scores remained significantly below the experimental group's achievements. More notably, the control group demonstrated regression in critical higher-order competencies, including problem identification, analysis and reasoning, and decision-making capabilities (Fig. 1).

Self-directed learning development

The experimental group's self-directed learning capabilities showed particular advancement in two critical domains: resource utilization and reflective learning, achieving scores of 15.67 ± 1.51 and 28.00 ± 1.55, respectively. These metrics significantly surpassed the control group's performance ($P < 0.05$). The control group's developmental trajectory revealed concerning stagnation in resource utilization (remaining constant at 5.67 ± 1.51 from Week 4 to Week 8) and modest improvement in reflective learning (from 16.00 ± 1.55 to 23.00 ± 1.55). However, the magnitude of improvement in the control group substantially lagged behind the experimental group's progressive development (Fig. 2).

Knowledge mastery development analysis

Longitudinal assessment of knowledge mastery revealed distinctive patterns between groups across the study period. At baseline, both groups demonstrated comparable performance (experimental: 49.17 ± 7.36, control: 52.50 ± 6.12, $P = 0.414$). By Week 4, both groups showed substantial improvement, with the experimental group achieving 99.17 ± 2.04 compared to the control group's 96.67 ± 4.08, though this difference did not reach statistical significance ($P = 0.209$).

The Week 8 follow-up assessment demonstrated sustained high performance in the experimental group (98.33 ± 2.58) while revealing a slight decline in the control group (95.00 ± 0.00). This difference achieved statistical significance ($P = 0.010$), suggesting that the scaffolded teaching approach supported better long-term knowledge retention. The experimental group maintained consistently high scores with minimal variation, indicating stable knowledge acquisition across participants (Fig. 3).

This pattern aligns with the broader findings of enhanced learning outcomes in the experimental group,

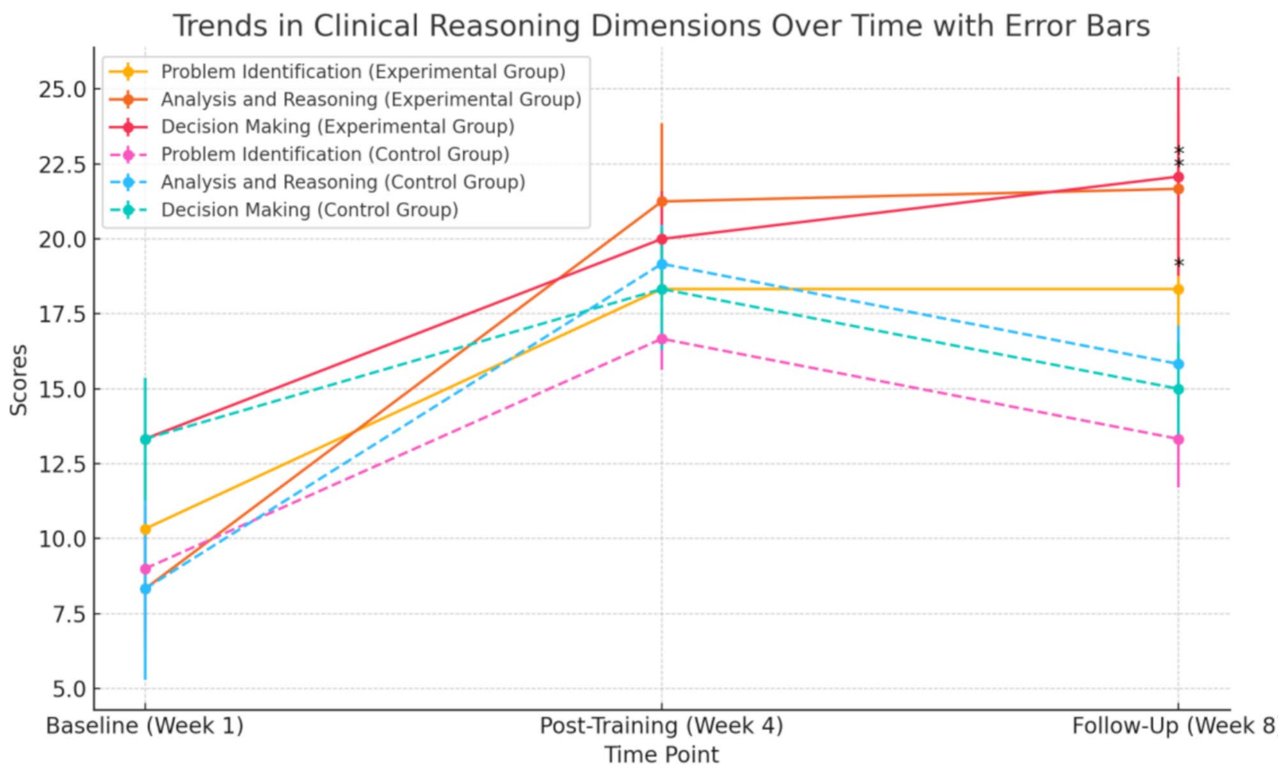

Fig. 1 Longitudinal Analysis of Clinical Reasoning Dimensions
Note: The figure depicts the longitudinal development of three fundamental clinical reasoning dimensions (Problem Identification, Analysis and Reasoning, and Decision Making) across three assessment time points: Baseline (Week 1), Post-Training (Week 4), and Follow-Up (Week 8). Solid lines represent the experimental group's performance trajectories, while dashed lines indicate the control group's progression. Error bars represent standard deviation (± SD), and asterisks (*) denote statistically significant differences between groups ($p < 0.05$). The experimental group demonstrated consistent improvement across all dimensions throughout the study period, whereas the control group showed initial improvement at Week 4 followed by a significant decline at Week 8. The assessment utilized standardized scoring criteria with maximum possible points as follows: Problem Identification (20 points), Analysis and Reasoning (25 points), and Decision Making (25 points). The divergent trajectories between groups became particularly pronounced during the follow-up period, suggesting enhanced retention of clinical reasoning capabilities in the experimental group

particularly in knowledge integration and application. The sustained high performance in the experimental group suggests that scaffolded case-based learning may support more robust knowledge retention compared to traditional teaching methods.

Discussion

Overview of study findings and theoretical alignment

This randomized controlled trial evaluated the efficacy of integrating scaffolding teaching methodology with case-based discussion (CBD) in medical resident education, comparing this innovative approach against traditional lecture-based instruction. The investigation revealed compelling evidence supporting the superiority of the integrated teaching model across multiple educational domains.

It is important to clarify that this investigation compared an integrated scaffolding with case-based discussion approach against traditional lecture-based teaching that also incorporated case illustration. This research design allows us to establish the efficacy of the integrated approach compared to lecture-based instruction, but does not permit evaluation of the specific contribution of scaffolding within case-based discussion methodology. This distinction is crucial for the accurate interpretation of our findings.

The study's primary findings demonstrated that the scaffolding teaching approach significantly enhanced residents' clinical reasoning capabilities and self-directed learning competencies while achieving exceptional levels of teaching satisfaction. Moreover, the methodology showed marked advantages in knowledge acquisition and retention, particularly in complex clinical scenarios.

These outcomes align with our initial theoretical framework, which posited that scaffolding teaching methodologies would prove particularly effective in complex case discussions. The results substantiate this hypothesis, demonstrating that this integrated approach creates an optimal learning environment for developing comprehensive clinical competencies. The methodology's success appears to derive from its systematic support of self-directed learning processes, facilitation of knowledge

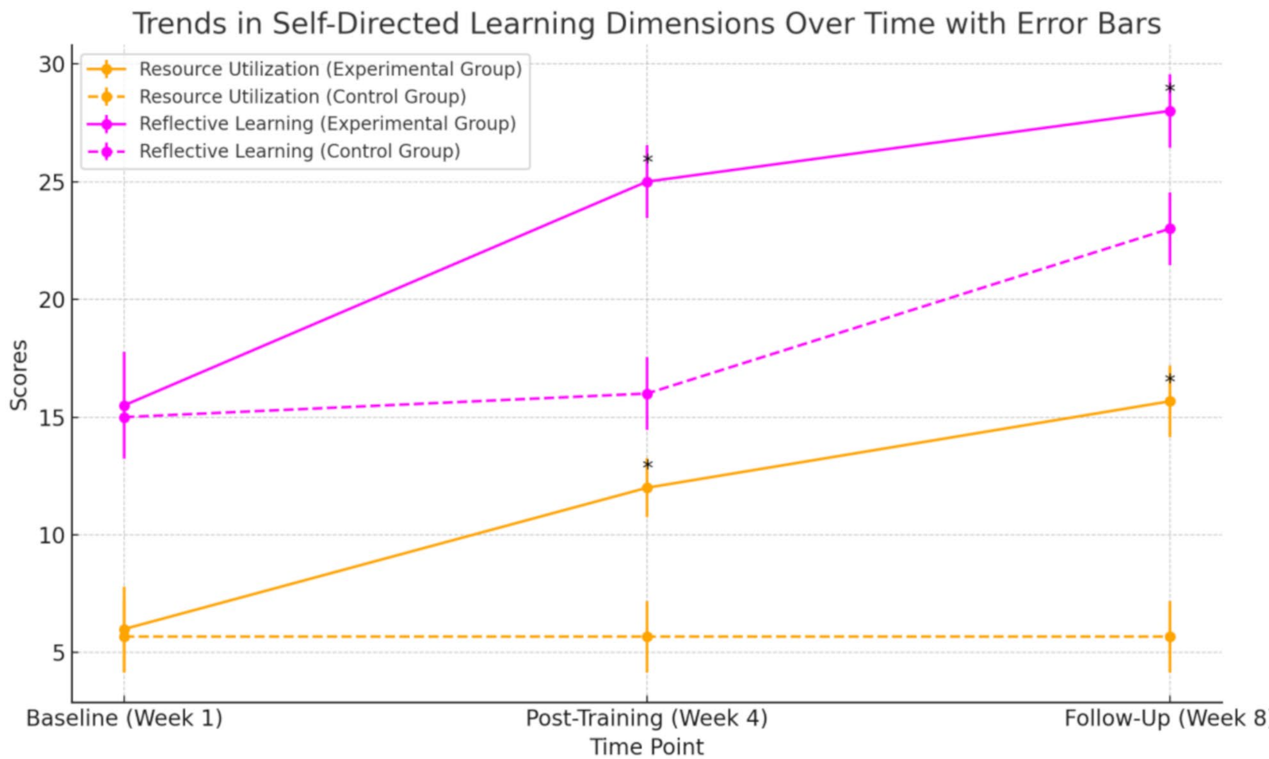

Fig. 2 Longitudinal Trends in Self-Directed Learning Components
Note: The figure demonstrates the progression of two key self-directed learning components (Resource Utilization and Reflective Learning) across three assessment points: Baseline (Week 1), Post-Training (Week 4), and Follow-Up (Week 8). Solid lines represent the experimental group's performance, while dashed lines indicate the control group's trajectory. Error bars represent standard deviation (± SD). Asterisks (*) indicate statistically significant differences between groups ($p < 0.05$). Maximum possible scores: Resource Utilization (20 points) and Reflective Learning (30 points). The experimental group showed consistent improvement in both dimensions, while the control group demonstrated minimal change in Resource Utilization and modest improvement in Reflective Learning

integration, and creation of interactive educational environments.

The sustained improvement in performance metrics, particularly in higher-order cognitive domains, suggests that this pedagogical approach not only enhances immediate learning outcomes but also promotes durable skill development. This finding has significant implications for medical education, particularly in the context of complex clinical scenarios that require sophisticated decision-making capabilities.

Theoretical foundation and evidence base

The scaffolding teaching methodology, grounded in constructivist learning theory, implements a structured support framework designed to facilitate learner progression within their Zone of Proximal Development (ZPD) [10, 16]. This pedagogical approach systematically provides calibrated assistance that enables learners to transcend current limitations, ultimately achieving independent operational competency through gradual withdrawal of instructional support.

Empirical evidence has consistently demonstrated the efficacy of scaffolding teaching in enhancing higher-order cognitive functions and practical skill development [17–19]. The methodology's particular strength lies in its application to medical education, where it has shown remarkable effectiveness in developing sophisticated clinical reasoning capabilities. Through its emphasis on dynamic support mechanisms and systematic task decomposition, the approach facilitates comprehensive skill development while maintaining learner engagement.

Postma and colleagues' seminal research demonstrated that scaffolding teaching, when integrated with contextualized learning environments, produced significant improvements in both task completion efficiency and analytical decision-making capabilities [20]. The current investigation's findings align with and extend this established research base, providing robust evidence for the effectiveness of combining scaffolding teaching with case-based discussion (CBD) in complex clinical education scenarios.

The integration of scaffolding principles with CBD creates a synergistic educational environment that promotes

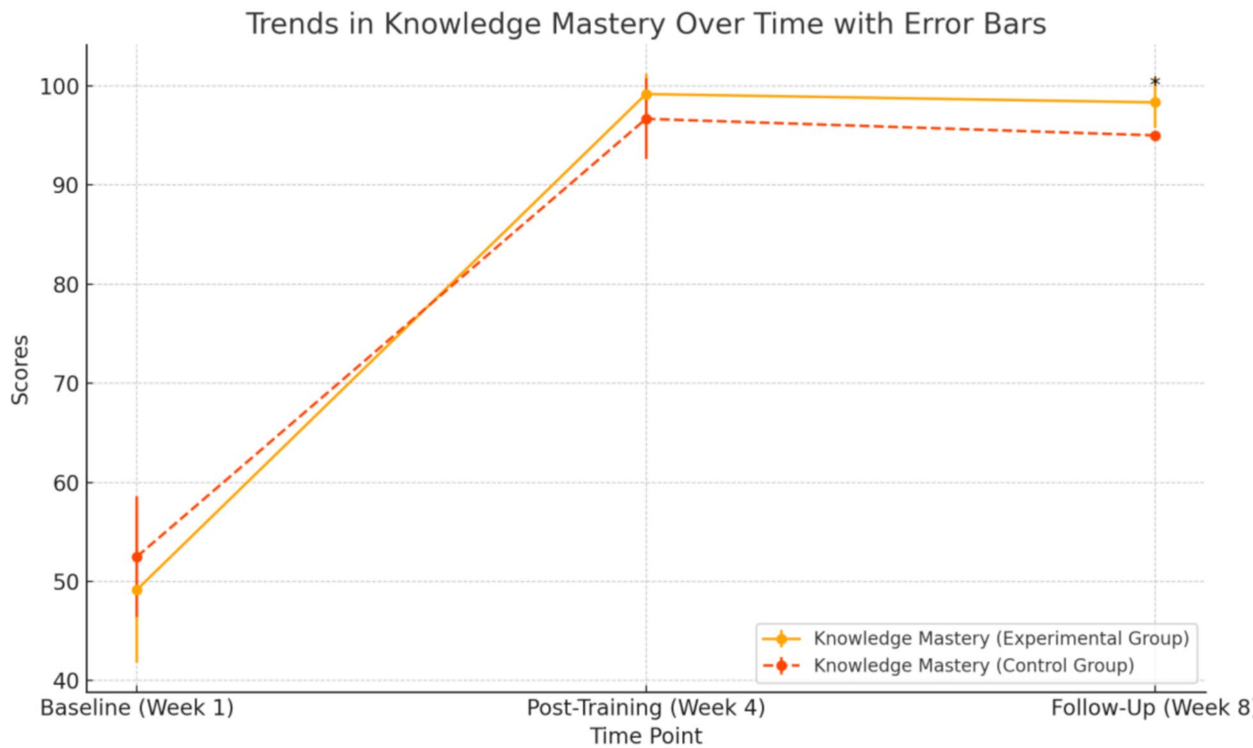

Fig. 3 Longitudinal Analysis of Knowledge Mastery Development
Note: The figure illustrates the progression of knowledge mastery scores across three assessment points: Baseline (Week 1), Post-Training (Week 4), and Follow-Up (Week 8). The experimental group (solid line) and control group (dashed line) demonstrated comparable baseline performance, followed by substantial improvement at Week 4. The experimental group maintained high performance through Week 8 (98.33 ± 2.58), while the control group showed slight decline (95.00 ± 0.00). Error bars indicate standard deviation (± SD), and asterisks (*) denote statistically significant between-group differences ($p < 0.05$). Knowledge mastery was assessed using a standardized examination with a maximum score of 100 points

active learning engagement while providing structured support for skill development. This combination appears particularly effective in complex case teaching, where learners must simultaneously develop multiple competencies while maintaining high standards of clinical decision-making.

Course design and implementation framework

The educational intervention was structured as a comprehensive four-week program, with weekly sessions of 1.5 h duration, carefully designed to optimize learning outcomes through systematic skill development. The curriculum architecture incorporated a progressive approach that aligned with both the inherent complexity of the educational content and the anticipated cognitive development trajectory of resident physicians.

The course implementation followed a methodically staged progression, beginning with foundational knowledge establishment and advancing through increasingly complex clinical scenarios. This systematic approach enabled the integration of sophisticated case discussions and high-fidelity simulation training at appropriate developmental intervals, ensuring that advanced concepts were introduced only after learners had demonstrated mastery of prerequisite knowledge components.

The scaffolded support framework was calibrated to provide optimal assistance at each learning stage, with systematic reduction in support levels as learners demonstrated increasing competency. This dynamic adjustment of instructional support facilitated the development of autonomous clinical decision-making capabilities while maintaining appropriate safety margins for learning complex medical concepts.

The integration of simulation training and complex case discussions was strategically timed to coincide with learners' progressive skill development, ensuring that these advanced learning modalities enhanced rather than overwhelmed developing clinical competencies. This careful orchestration of learning activities created an optimal environment for the systematic development of sophisticated clinical reasoning capabilities.

Core principles of the scaffolding teaching implementation

Strategic support and progressive autonomy

The experimental protocol implemented scaffolding principles through carefully calibrated support mechanisms [19, 21]. Using the complex case of anesthetic management for hypertrophic obstructive cardiomyopathy (HOCM), the program established a systematic progression from intensive guidance to autonomous practice. Initial phases emphasized foundational knowledge acquisition and problem identification, transitioning methodically to advanced clinical simulations while gradually reducing instructor intervention. The comprehensive evaluations at Weeks 4 and 8, particularly in managing complex scenarios such as intraoperative hemodynamic instability and postoperative heart failure, demonstrated the successful implementation of both the supportive "construction" and autonomous "dismantling" phases of the scaffolding methodology.

Authentic clinical context and problem-based learning

The program emphasized real-world clinical complexity through carefully designed problem scenarios [22, 23]. Case tasks focused on sophisticated clinical challenges, such as the hemodynamic implications of left ventricular outflow tract obstruction. By presenting high-complexity scenarios including intraoperative hypotension and tachycardia, the program facilitated integration of theoretical knowledge with practical application. This approach enhanced clinical reasoning capabilities through systematic development of problem identification, analytical reasoning, and decision-making skills.

Dynamic feedback and iterative improvement

The implementation incorporated comprehensive feedback mechanisms essential to scaffolding methodology [24, 25]. Regular evaluation cycles provided opportunities for strategy refinement and skill enhancement. Following simulated operations, instructors delivered detailed assessments and targeted improvement recommendations, enabling residents to optimize their clinical decision-making processes. The incorporation of feedback adoption metrics ensured systematic evaluation of residents' ability to integrate and apply instructional guidance.

Learner-centered methodology

The program design prioritized learner autonomy to develop self-directed learning capabilities [26, 27]. Structured autonomous learning activities, including resource utilization and reflective practice, were implemented with appropriate guidance frameworks. This approach resulted in significant improvements in self-directed learning competencies, particularly evident in enhanced resource utilization and reflective learning capabilities. The systematic development of these skills supports the long-term professional development of resident physicians.

The integration of these core principles created a comprehensive educational environment that effectively balanced structured support with progressive autonomy, resulting in enhanced clinical competencies and sustained learning engagement.

Case selection and educational design rationale

The selection of "anesthetic management of hypertrophic obstructive cardiomyopathy (HOCM)" as the primary teaching case represented a strategic decision that aligned multiple educational objectives. This choice was predicated on both the inherent clinical complexity of HOCM management and its exceptional utility as a vehicle for implementing scaffolding teaching principles in medical education.

The case selection offered distinct pedagogical advantages. HOCM's complex pathophysiology and high-risk management profile created an optimal framework for enhancing residents' clinical decision-making capabilities and comprehensive skill development. The progressive nature of the disease's pathophysiological manifestations aligned naturally with the incremental, problem-driven approach fundamental to scaffolding teaching methodology.

The experimental group's teaching design leveraged this alignment to create a sophisticated learning environment that fulfilled dual objectives: adherence to core scaffolding principles and delivery of clinically relevant content. The implementation of dynamic simulation scenarios and structured problem-solving exercises facilitated deep integration of theoretical knowledge with practical clinical applications. This approach created multiple opportunities for residents to develop and refine their clinical competencies in a controlled educational environment.

The careful orchestration of these elements established a robust educational framework that not only enhanced immediate learning outcomes but also created a foundation for continued professional development. By providing residents with structured exposure to complex clinical scenarios, the program developed both the technical skills and clinical judgment essential for future practice in high-stakes medical environments.

Analysis of week 4 performance differentials

Implementation ability enhancement

The Week 4 evaluation revealed significant performance disparities between the experimental and control groups, specifically in implementation ability within the clinical reasoning domain. However, other dimensions including problem identification, analysis and reasoning, decision-making, and feedback adoption showed no statistically significant differences. This distinctive pattern warrants careful analysis of contributing factors.

Key factors driving implementation competency

Practice-Based Learning Integration The scaffolding teaching methodology's emphasis on simulation-based training and practical application proved particularly effective in enhancing implementation skills [28, 29]. The experimental group engaged in sophisticated scenario-based simulations and iterative dynamic tasks, facilitating the transformation of theoretical knowledge into actionable clinical competencies. Previous research has validated the efficacy of scaffolding teaching in medical education, particularly in developing complex clinical decision-making capabilities [30, 31]. Real-Time Feedback Mechanisms The incorporation of immediate feedback systems during scenario simulations provided critical support for skill refinement. This dynamic feedback process enhanced both operational precision and participant confidence [32, 33]. In contrast, the control group's reliance on theoretical instruction limited opportunities for practical skill development.Experiential Learning Focus Implementation ability, being fundamentally dependent on hands-on experience [34], demonstrated particular responsiveness to the experimental group's practice-oriented approach. Research indicates that implementation skills require reinforcement through practical application, a requirement not adequately met through theoretical instruction alone [35, 36].

Analysis of non-differential dimensions

The absence of significant differences in other clinical reasoning dimensions can be attributed to several factors:1. Baseline Equivalence Initial evaluations demonstrated comparable clinical reasoning capabilities between groups in problem identification, analysis, and decision-making, potentially limiting the scope for differential improvement.2. Theoretical Content Consistency Despite methodological differences, both groups received similar theoretical instruction in core concepts, potentially moderating performance disparities in knowledge-based dimensions.3.Temporal Requirements for Skill Development Higher-order cognitive processes typically require extended periods for full development [37, 38]. The four-week intervention period may have been insufficient for significant differentiation in complex cognitive domains.4. This analysis suggests that while scaffolding teaching demonstrates particular efficacy in developing implementation skills, the development of higher-order clinical reasoning capabilities may require longer intervention periods for meaningful differentiation.

Analysis of simulation-based training effects

The experimental group's simulation-based training demonstrated a pronounced impact on practical skill development, while showing more limited effects on theoretical reasoning capabilities. This pattern aligns with established research findings regarding the differential impact of simulation-based medical education. Research evidence indicates that simulation-based training exhibits particular efficacy in developing complex procedural skills that require intensive hands-on practice [23, 29]. However, its influence on higher-order cognitive functions, such as theoretical reasoning and conceptual understanding, demonstrates more modest outcomes [30, 31]. This differential effect can be attributed to the fundamental nature of simulation-based education, which primarily facilitates the acquisition and transfer of procedural knowledge while providing less robust support for conceptual knowledge development [32, 39]. The observed performance patterns reflect this inherent characteristic of simulation-based training. While participants demonstrated marked improvement in practical implementation skills, the development of more abstract cognitive capabilities showed less pronounced advancement. This finding suggests that while simulation-based training serves as an excellent vehicle for developing practical clinical competencies, it may need to be supplemented with additional educational strategies to fully support the development of higher-order cognitive abilities.

This analysis provides important insights for the design of medical education programs, suggesting that optimal outcomes may require a balanced approach that combines simulation-based training with other pedagogical methods specifically targeted at developing theoretical reasoning capabilities.

Analysis of self-directed learning outcomes at week 4

Resource utilization and reflective learning differentials

The Week 4 evaluation revealed significant performance disparities between the experimental and control groups in self-directed learning capabilities, particularly in resource utilization and reflective learning dimensions. This divergence can be attributed to fundamental differences in pedagogical approaches.The experimental group's methodology incorporated active learning requirements that directly enhanced resource utilization capabilities. Participants engaged in systematic literature retrieval, data analysis, and management plan development as integral components of case discussions and simulation exercises. This task-driven approach significantly enhanced both resource utilization competencies and self-directed learning motivation [40].The integration of structured feedback mechanisms and emphasis on reflective learning strategies further contributed to marked improvements in reflective learning capabilities [41]. Instructor feedback was systematically incorporated into the learning process, creating opportunities for continuous improvement and skill refinement. Conversely, the control group's reliance on instructor-provided materials limited opportunities for active skill development, resulting in comparatively lower performance in both resource utilization and reflective learning domains.

Engagement and interactive learning effects
The experimental group's implementation of small-group discussions and simulation exercises created an environment that fostered high levels of student engagement and interactivity. This enhanced engagement directly contributed to increased motivation for self-directed learning and overall satisfaction with the educational process.The control group's traditional lecture-based approach, while effective for content delivery, demonstrated limitations in fostering interactive learning environments. This reduced interactivity negatively impacted both learning motivation and overall educational experience, contributing to lower satisfaction levels compared to the experimental group.These findings suggest that the integration of active learning strategies and structured feedback mechanisms plays a crucial role in developing self-directed learning capabilities and enhancing overall educational outcomes. The significant differences in teaching satisfaction between groups further validate the effectiveness of this integrated approach to medical education.

Week 8 follow-up analysis: long-term effects of scaffolding teaching

Expansion of cognitive benefits
The Week 8 follow-up assessment revealed that the experimental group's advantages had expanded beyond implementation skills to encompass higher-order cognitive dimensions, including problem identification, analytical reasoning, and decision-making capabilities. This comprehensive improvement extended to knowledge acquisition, demonstrating statistically significant differences between groups [12]. These findings suggest that scaffolding teaching's task-driven, contextualized approach generates cumulative benefits for higher-order cognitive abilities through sustained knowledge internalization and reflective practice.

Sustained enhancement of self-directed learning
The experimental group maintained significant advantages in self-directed learning capabilities, particularly in resource utilization and reflective learning dimensions. This sustained improvement can be attributed to the systematic integration of dynamic instructor feedback and structured instructional design [42]. The consistent enhancement of these capabilities indicates the long-term effectiveness of the scaffolding methodology in developing autonomous learning skills.

Control group performance trajectory
While the control group demonstrated modest improvements in implementation ability and feedback adoption following their Week 4 performance review, their development showed notable limitations. Higher-order cognitive functions, including problem identification, analytical reasoning, and decision-making, exhibited concerning regression. This pattern suggests fundamental limitations in traditional lecture-based teaching for developing complex clinical competencies [28]. The observed decline may be attributed to insufficient systematic training, inadequate support for advanced cognitive development, and limited transfer of learning motivation.

Long-term educational impact
The scaffolding teaching model's emphasis on interactivity, practical application, and systematic design demonstrated both immediate and long-term benefits. Beyond the initial enhancement of implementation skills, the methodology proved particularly effective in fostering sustained development of higher-order cognitive abilities, self-directed learning capabilities, and knowledge acquisition. These advantages became increasingly evident at the Week 8 follow-up evaluation [43], validating the long-term efficacy of this innovative educational approach.

This comprehensive analysis supports the conclusion that scaffolding teaching provides a robust framework for developing both immediate practical skills and sustained cognitive capabilities in medical education.

Study innovation and methodological contributions

Integration of advanced teaching methodologies
This investigation presents a significant advancement in medical education by successfully integrating scaffolding teaching principles with case-based discussion for complex clinical scenarios. This integrated approach was evaluated as a unified educational model in comparison with traditional lecture-based teaching, rather than assessing the independent contribution of scaffolding within case-based discussion. This novel methodology addresses a critical gap in medical education research regarding the application of advanced teaching methodologies in complex clinical training. The implementation of dynamic simulation tasks created a structured environment for developing both practical implementation skills and higher-order cognitive abilities within authentic clinical contexts. The introduction of a comprehensive, multidimensional assessment framework provided robust evidence for the model's effectiveness, particularly in evaluating critical components such as feedback integration and reflective learning capabilities.

Validation in complex clinical scenarios
The study demonstrates the efficacy of scaffolding teaching methodology in managing highly complex clinical cases, specifically in the context of anesthetic management for patients with hypertrophic obstructive cardiomyopathy (HOCM). Through systematic comparison with traditional lecture-based instruction, the research illuminates both the limitations of conventional teaching approaches and the distinct advantages of scaffolding methodology. This comparative analysis provides valuable insights for medical education program development.

Long-term impact assessment
A distinguishing feature of this research is its examination of longitudinal outcomes through an extended 8-week follow-up period, departing from the typical focus on immediate educational effects. The findings reveal sustained improvements in knowledge internalization and reflective practice, providing compelling evidence for the long-term efficacy of the scaffolding teaching approach. These results offer important implications for the design and implementation of medical education programs.

Theoretical and practical implications
The study's innovations extend beyond theoretical contributions to scaffolding teaching principles, offering practical frameworks for implementing case-based discussion and contextualized learning in medical education. This research establishes a foundation for future investigations into advanced teaching methodologies while providing actionable insights for medical education practitioners. The demonstrated success in complex clinical scenarios suggests broad applicability across various medical education contexts.

This comprehensive analysis validates the effectiveness of integrated scaffolding teaching approaches while establishing new pathways for advancing medical education methodology.

Study limitations and future research directions
Methodological constraints
The study faced several methodological limitations that warrant consideration. The relatively small sample size potentially impacted the statistical power and generalizability of findings. Additionally, while the eight-week follow-up period provided valuable insights into sustained learning outcomes, a longer observation period would enhance understanding of long-term effects. The standardization of teaching implementation across different instructors and settings remains an area requiring further refinement.

Assessment and analysis limitations
The research methodology demonstrated certain analytical constraints. The quantitative analysis of learning behaviors and motivational factors could have been more comprehensive, potentially overlooking important behavioral patterns and psychological factors influencing learning outcomes. Furthermore, the evaluation framework did not fully capture the development of interpersonal and communication skills, which are crucial components of medical practice.

Scope and generalizability
The study's focus on a single clinical case, while allowing for detailed analysis, potentially limits the broader applicability of findings. The exclusive use of hypertrophic obstructive cardiomyopathy (HOCM) as the teaching case, though complex and representative, may not fully reflect the diverse challenges encountered in medical practice. Additionally, the research offered limited exploration of potential improvements to traditional lecture-based teaching methods, which might still play a valuable role in medical education.

Future research opportunities
These limitations suggest several promising directions for future research:

(1) Design comparative studies specifically examining case-based learning with and without scaffolding to evaluate the distinct contribution of scaffolding elements within case-based discussion methodology.
(2) Expanding the study scope to include larger sample sizes and diverse clinical scenarios.
(3) Implementing longer follow-up periods to better understand sustained learning effects.
(4) Developing more comprehensive assessment tools for measuring soft skills and learning behaviors.
(5) Investigating potential hybrid approaches that combine scaffolding teaching with enhanced traditional methods.
(6) Exploring the application of this teaching model across different medical specialties and learning contexts.

These identified limitations and future research directions provide valuable guidance for continuing refinement and expansion of scaffolding teaching methodologies in medical education.

Concluding analysis and implications
This research demonstrates the significant efficacy of integrating scaffolding teaching methodology with case-based discussion in medical education. The study provides compelling evidence for enhanced resident

performance across multiple domains: clinical reasoning capabilities, self-directed learning competencies, and knowledge acquisition. Particularly noteworthy is the sustained improvement observed in complex case management scenarios.

It warrants emphasis that due to the research design comparing an integrated scaffolding-case-based approach with traditional lecture-based teaching, the study cannot definitively attribute the observed improvements to scaffolding specifically, case-based discussion, or their synergistic interaction. This investigation establishes the effectiveness of the integrated approach while simultaneously identifying important directions for future research, particularly regarding the assessment of scaffolding's unique contribution within case-based learning environments.

The implementation of dynamic support mechanisms and contextualized learning environments has established a robust framework for medical education reform. This innovative approach addresses critical gaps in existing teaching methodologies while providing systematic evidence for its effectiveness in developing advanced clinical competencies. The sustained benefits observed throughout the study period validate the long-term value of this integrated teaching approach.

Beyond its immediate educational outcomes, this research contributes significant theoretical and practical insights to the field of medical education. The findings provide a foundation for optimizing residency teaching programs and advancing professional development in medical training. The demonstrated success in complex clinical scenarios suggests broad applicability across various medical education contexts.

This study advances our understanding of effective pedagogical approaches in medical education while establishing practical frameworks for implementation. The findings support the continued development and refinement of integrated teaching methodologies that combine structured support with progressive autonomy in clinical education. These results provide valuable guidance for medical educators and program developers seeking to enhance the effectiveness of their training programs.

The study's outcomes underscore the potential for systematic improvement in medical education through carefully designed and implemented teaching methodologies. This research establishes a foundation for future innovations in medical education while providing immediate, practical benefits for current training programs.

Abbreviations

CBD	Case-Based Discussion
STM	Scaffolding Teaching Model
ZPD	Zone of Proximal Development
HOCM	Hypertrophic Obstructive Cardiomyopathy
DOPS	Direct Observation of Procedural Skills
SDLRS	Self-Directed Learning Readiness Scale
ASA	American Society of Anesthesiologists
CT	Computed Tomography
SAM	Systolic Anterior Motion
SPSS	Statistical Package for the Social Sciences

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-025-07236-1.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

L.Z. conceptualized the study, designed the methodology, led research implementation, and prepared the main manuscript. C.C. contributed to research implementation and conducted outcome evaluation and assessment. R.W. was responsible for data collection and management. Y.Q. provided senior academic supervision, reviewed the manuscript, and made critical revisions. All authors reviewed and approved the final manuscript.

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Data availability

The complete dataset supporting the findings of this study is contained within the manuscript and supplementary materials. Additional data are available from the corresponding author upon reasonable academic request with appropriate justification.

Declarations

Ethics approval and consent to participate

This study was conducted with approval from the Ethics Committee of Ningbo Medical Center Li Huili Hospital (Approval Number: KY2022PJ193). All participants provided written informed consent prior to study enrollment. The research methodology adhered strictly to relevant guidelines and regulations governing human subject research.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Anesthesia, The Affiliated Lihuili Hospital of Ningbo University, Ningbo 315040, Zhejiang, P.R. China

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