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Effectiveness of a CDIO-based Blended Teaching Model on Learning Outcomes among Cardiovascular Nursing Interns: A Quasi-Experimental Study

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Abstract: Introduction Clinical internship is a pivotal stage in nursing education, yet traditional cardiology preceptorship remains instructor-centered and lecture-based, inadequately fostering self-directed learning and clinical reasoning. Integrating the CDIO framework with Kolb's experiential learning theory into a blended online-to-offline model may offer a comprehensive solution. This study aimed to develop and evaluate this integrated model for cardiology nursing interns. **Methods** In this quasi-experimental study, 201 nursing interns were assigned to a control group (traditional lecture-based learning, n=100) or an experimental group (blended CDIO-experiential learning model, n=101). Self-directed learning, critical thinking, learning engagement, and clinical practice readiness were measured pre- and post-intervention, together with theoretical/skills examinations and teaching satisfaction. **Results** The experimental group significantly outperformed the control group on all outcomes: theoretical scores (d=0.81), skills scores (d=0.74), self-directed learning (d=3.53), critical thinking (d=4.59), learning engagement (d=4.02), clinical practice readiness (d=2.26), and teaching satisfaction (d=2.40) (all $P<0.001$); improvement magnitudes were also significantly greater (d=1.05–2.92). Skills scores (β=0.505) and critical thinking (β=0.280) independently predicted theoretical achievement. **Discussion** The blended CDIO-experiential learning model substantially enhances nursing interns' competencies and educational outcomes with large-to-very-large effect sizes, offering a transferable paradigm for clinical teaching reform. Long-term effects and generalizability require further multicenter validation.

Keywords: CDIO; Experiential Learning; Blended Teaching; Nursing Interns; Critical Thinking.

1. Introduction

Clinical internship is a critical transitional phase in which nursing students move from theoretical learning to clinical practice and from the student role to that of a professional nurse, and it is an indispensable component of nursing education [1,2].Cardiology is characterized by acute onset, rapid progression, a high proportion of critically ill patients, and complex nursing procedures [3,4], imposing high demands on interns' professional knowledge, clinical reasoning, and practical skills. Traditional cardiology preceptorship has predominantly used a "shadowing" approach in which instructors demonstrate and students observe and imitate, leaving students passive and inadequately cultivating self-directed learning and clinical reasoning [5,6]. Although case-based and problem-based teaching have been introduced, most reports address isolated pedagogical methods and lack a systematic framework centered on progressive competency development. Reforming preceptorship to enhance interns' comprehensive competencies is therefore an urgent issue in nursing education.

Novel teaching models have been progressively introduced into clinical nursing education [7].The CDIO (Conceive–Design–Implement–Operate) framework comprises four phases and emphasizes project-driven, practice-oriented learning in which students engage in the whole process from conception to operation to develop practical abilities and overall competencies [8–10]; it has been applied successfully in courses such as surgical nursing [11,12].Kolb's experiential learning theory (1984) posits that learning is "the process whereby knowledge is created through the transformation of experience," comprising four cyclical stages—concrete experience, reflective observation, abstract conceptualization, and active experimentation [13–15]—and holds that students construct knowledge through firsthand experience, reflection, and internalization in real or simulated contexts; it has shown promising prospects in nursing education [16–18].

Blended online-to-offline teaching [19,20] integrates the standardization and repeatability of online theoretical learning with the interactivity and experiential nature of offline practical teaching, and is emerging as a key direction for clinical nursing education reform. Previous studies show that blended scenario-based simulation teaching improves nursing undergraduates' clinical reasoning, clinical practice ability, and teaching satisfaction [21,22], and that blended teaching based on the O-AMAS model benefits interns' examination scores, critical thinking, and self-directed learning in cardiology preceptorship [23].However, the literature has three limitations: (1) most studies apply either the CDIO framework or experiential learning theory in isolation, and none has integrated both to guide full-cycle instructional design; (2) most reports use single-arm pre–post designs without concurrent controls, making it difficult to exclude confounding from time and maturation effects; and (3) outcome assessment has concentrated on examination scores, with insufficient attention to indicators of professional socialization such as learning engagement and clinical practice readiness. To address these gaps, this study constructs a blended model underpinned by Kolb's experiential learning theory as the pedagogical framework

and the CDIO philosophy as the process backbone, and evaluates its effectiveness in a quasi-experimental design with concurrent controls.

2. Methods

2.1. Study Design and Ethics

This study adopted a non-randomized controlled quasi-experimental design and followed the TREND (Transparent Reporting of Evaluations with Nonrandomized Designs) statement reporting guidelines. Because clinical internship scheduling precluded individual randomization, a ward-based group assignment design was implemented.

The study protocol was approved by the Ethics Committee of Bengbu First People's Hospital (approval No. BBYYLWPJ2026022). All participants provided written informed consent, and the study was conducted in accordance with the Declaration of Helsinki. Questionnaires were anonymous, and data were de-identified before entry, with access restricted to the research team.

2.2. Participants

Using convenience sampling, full-time nursing interns who completed their clinical rotation in the Department of Cardiovascular Medicine at Bengbu First People's Hospital between June 2025 and March 2026 were recruited. Inclusion required full-time secondary vocational, college, or baccalaureate interns in their first cardiovascular rotation who gave informed consent and participated voluntarily; exclusion applied to those with cumulative leave >1 week during the internship, withdrawal or early transfer to another department, or prior cardiology internship experience.

Of 205 eligible interns assessed during the study period, 4 were excluded (discontinuation of internship), yielding 201 participants, all of whom completed the full assessment battery with no attrition. Participants came from 16 educational institutions: 24 (11.9%) secondary vocational, 158 (78.6%) junior college, and 19 (9.5%) baccalaureate students. Ward 1 served as the control group (n=100) and Ward 2 as the experimental group (n=101); the teaching duration was 2 months for both groups.

2.3. Sample Size Estimation

A priori sample size was estimated using G*Power 3.1. With α=0.05 (two-tailed), statistical power 1-β=0.80, and an assumed effect size of Cohen's d=0.40 (moderate effect, referenced to a median effect size of 0.51 reported in a meta-analysis of comparable nursing education studies [24]), an independent-samples t-test indicated that at least 84 participants per group were required.The actual enrolment of 100 and 101 participants met the required statistical power.

2.4. Interventions

2.4.1. Control Group: Traditional LBL Teaching

The control group received traditional lecture-based learning (LBL): two centralized theoretical lectures per week (2 class hours each), one skills demonstration and practice session per week (2 class hours), and clinical shadowing practice during the remaining time.Teaching was predominantly instructor-led, with students listening, observing, and practicing alongside clinical staff.In experiential learning terms, LBL activities were concentrated in the "abstract conceptualization" phase.

2.4.2. Experimental Group: Blended Online-to-offline CDIO Teaching based on Experiential Learning Theory

The instructional design for the experimental group was guided by experiential learning theory as the pedagogical foundation and structured around the four CDIO phases as the procedural backbone, ensuring that every nursing intern experienced a complete learning cycle.

(1) Teaching team formation

A CDIO teaching team was established: one team leader (head nurse of the cardiology department), two deputy leaders, and four clinical instructors (all holding a bachelor's degree or above and certified as senior nurses with ≥5 years of cardiology preceptorship experience).The team received 16 hours of training on experiential learning theory and the CDIO approach and held weekly collective lesson-planning meetings.

(2)Conceive phase – corresponding to "reflective observation (RO)"

The teaching team restructured the cardiology internship into six clinical task modules: (a) perioperative care for acute coronary syndrome; (b) fluid management and symptom control in heart failure; (c) arrhythmia monitoring and emergency response coordination; (d) individualized care and health management in hypertension; (e) perioperative care for cardiac interventional procedures; and (f) comprehensive care for cardiovascular critical emergencies.

One day before each module, materials were delivered online: (a) micro-lecture videos (10–15 minutes); (b) procedural demonstration videos; (c) clinical case materials; and (d) guided reflective questions (e.g., "If you were the primary nurse, which patient issue would you address first, and why?").Students completed these before class and posted at least two reflective comments in the online group.

(3)Design phase – corresponding to "abstract conceptualization (AC)"

Students worked in small groups (3–4 per group) on the pre-released cases to complete nursing assessment, nursing diagnoses, goal setting, intervention plans, and emergency response protocols. Instead of providing direct answers, instructors guided conceptualization through metacognitive questioning (e.g., "What is your rationale for making this diagnosis?" "If the patient's blood pressure dropped further, what adjustments would you make to your plan?").

(4)Implement phase – corresponding to "concrete experience (CE)"

(a)Scenario introduction (15 min): An expanded clinical scenario was presented, and role assignments were clearly defined.

(b)Scenario-based simulation run (30–40 min): Students performed nursing procedures according to their assigned roles in a simulated ward setting, with the entire process video-recorded.

(c)Guided debriefing/review (30 min): The video recording was played back, and reflective debriefing was facilitated using the GAS (Gather–Analyze–Summarize) method.

(5) Operate phase – corresponding to "active experimentation (AE)"

At the end of each module, a structured assessment was organized and results were fed back one-on-one.Real clinical cases encountered during practice were anonymized and added to the case bank.Excellent performers received public recognition and bonus points; those below standard received tutoring and a make-up examination.Weekly team meetings

continuously optimized the teaching plan using learning analytics and feedback.

2.5. Outcome Measures

2.5.1. Primary Outcome: Educational Achievement

At the end of the internship, a unified theoretical examination (full score 100) and a practical skills assessment covering three procedures—electrocardiographic monitoring, infusion pump operation, and cardiopulmonary resuscitation (average score used)—were administered.

2.5.2. Secondary Outcomes

(1) Self-directed learning ability was measured with the Chinese version of the Self-Directed Learning Instrument (SDLI), validated for mainland Chinese nursing students by Shen et al[25] (4 dimensions, 20 items; Cronbach's α=0.916).

(2) Clinical thinking ability was measured with the Chinese version of the Critical Thinking Disposition Inventory (CTDI-CV), revised by Peng et al[26] (7 dimensions, 70 items, 6-point Likert format; total scores 70–420, with higher scores indicating a stronger critical thinking disposition; Cronbach's α=0.90).

(3) Learning engagement was measured with the Chinese version of the Learning Engagement Scale, adapted by Fang et al[27] from Schaufeli et al.'s Utrecht Work Engagement Scale–Student version (3 dimensions, 17 items, scored 1–7, with higher scores indicating greater engagement; Cronbach's α=0.82–0.95).

(4) Clinical practice readiness was assessed with the Chinese version of the Casey-Fink Readiness for Practice Scale (CFRPS), validated by Song et al[28] (4 dimensions, 19 items; total scores 19–76, with higher scores indicating greater readiness; Cronbach's α=0.893).

(5) Teaching satisfaction was evaluated with the Clinical Internship Satisfaction Scale for nursing students developed by Du et al[29] (5 dimensions, 37 items, 5-point Likert format; total scores 37–185, with higher scores indicating greater satisfaction; Cronbach's α=0.965, Guttman split-half reliability 0.885).

2.6. Statistical Analysis

Analyses were performed using SPSS 26.0 and R 4.2. Continuous variables are reported as mean ± standard deviation and categorical variables as frequencies and percentages. Normality was assessed with the Shapiro–Wilk test and homogeneity of variances with Levene's test. Between-group comparisons used independent-samples t-tests (Welch's correction for unequal variances) or chi-square tests, with Cohen's d and 95% confidence intervals reported. Within-group pre–post comparisons used paired-samples t-tests with mean differences and 95% confidence intervals. ANCOVA compared post-test scores between groups with baseline scores as covariates. For the four secondary outcomes, between-group comparisons were adjusted by the Benjamini–Hochberg method to control the false discovery rate (FDR, q=0.05).Pearson correlation analysis explored inter-variable relationships. Theoretical examination scores were the dependent variable, and all variables with P<0.10 in univariate analysis were entered en bloc into a multiple linear regression model (not stepwise, to avoid effect-size bias and overfitting); unstandardized and standardized coefficients, 95% confidence intervals, and variance inflation factors were reported. The dataset was complete with no missing values. All tests were two-tailed, with α=0.05.

3. Results

3.1. Baseline Characteristics Comparison between the Two Groups

A total of 201 cardiology nursing interns were enrolled (Ward 1, n=100, 49.8%; Ward 2, n=101, 50.2%).No significant between-group differences were found in age, gender, educational level, family location, family income, personality type, academic performance, class cadre status, activity participation, reason for choosing nursing, first-choice major status, or only-child status (all P>0.05), indicating baseline comparability (Table 1).

Table 1. Comparison of baseline characteristics between the two groups of nursing interns

Variable	Ward 1(n=100)	Ward 2(n=101)	Test statistic	P-value
Age (years, mean ± SD)	20.43±0.98	20.41±0.89	t=0.18	0.855
Gender (male/female)	23/77	18/83	χ^2=0.54	0.462
Educational level(secondary vocational / junior college / baccalaureate)	15/74/11	9/84/8	χ^2=2.60	0.272
Family location (urban/rural)	60/40	60/41	χ^2=0.00	1.000
Family monthly income (<5k / 5–10k / >10k RMB)	18/63/19	22/66/13	χ^2=1.59	0.452
Personality type (extrovert/introvert/mixed)	31/35/34	36/29/36	χ^2=0.99	0.610
Academic performance at school (excellent/average/poor)	17/73/10	19/74/8	χ^2=0.34	0.846
Class cadre (yes/no)	18/82	18/83	χ^2=0.00	1.000
Active participation in activities (yes/no)	32/68	27/74	χ^2=0.44	0.506
Reason for choosing nursing (interest / others' advice / admission reassignment)	28/40/32	34/36/31	χ^2=0.80	0.670
Nursing as first choice (yes/no)	43/57	44/57	χ^2=0.00	1.000
Only child (yes/no)	61/39	69/32	χ^2=0.88	0.348
Self-directed learning (pre-test)	65.44±5.14	65.96±4.93	t=-0.73	0.465
Critical thinking (pre-test)	160.47±22.40	162.30±22.14	t=-0.58	0.562
Learning engagement (pre-test)	59.94±5.80	60.32±5.45	t=-0.47	0.636
CFRPS (pre-test)	27.90±5.82	28.63±5.87	t=-0.89	0.375

3.2. Primary Outcome: Comparison of Educational Achievement

At the end of the internship, theoretical examination scores in Ward 2 (91.49±6.69) were significantly higher than in Ward 1 (82.90±13.43) (Welch's t=-5.73, P<0.001; Cohen's d=0.81 [95% CI 0.52–1.10]), a moderate-to-large effect; Levene's test indicated unequal variances (P=0.002), so Welch's correction was applied.The overall skills score was also higher in Ward 2 (94.40±1.73 vs. 93.23±1.39; t=-5.28, P<0.001, d=0.74 [0.46–1.03]), as were all three individual skills: infusion pump operation (d=0.71), electrocardiographic monitoring (d=0.45), and cardiopulmonary resuscitation (d=0.43) (all P<0.01; Table 2).

Table 2. Comparison of educational achievement between the two groups (scores, mean ± SD)

Indicator	Ward 1(n=100)	Ward 2(n=101)	t-value	P-value	Cohen's d [95%CI]
Theoretical examination score	82.90±13.43	91.49±6.69	-5.73	<0.001	0.81 [0.52, 1.10]
Overall skills examination score	93.23±1.39	94.40±1.73	-5.28	<0.001	0.74 [0.46, 1.03]
Electrocardiographic monitoring	92.81±1.97	93.89±2.75	-3.21	0.002	0.45 [0.17, 0.73]
Infusion pump operation	93.88±2.10	95.24±1.72	-5.01	<0.001	0.71 [0.42, 0.99]
Cardiopulmonary resuscitation	93.01±2.35	94.08±2.65	-3.02	0.003	0.43 [0.15, 0.71]

3.3. Secondary Outcomes: Within-group Pre-post and Between-group Comparisons

Both groups improved significantly on all competency scores from pre- to post-intervention (all P<0.001).The magnitude of improvement was significantly greater in Ward 2 than in Ward 1: self-directed learning (16.69±6.20 vs. 4.58±2.37; t=-18.32, P<0.001, d=2.57), critical thinking (93.42±25.95 vs. 47.88±22.51; t=-13.30, P<0.001, d=1.87), learning engagement (25.26±7.72 vs. 7.55±3.67; t=-20.79, P<0.001, d=2.92), and clinical practice readiness (21.79±6.64 vs. 15.08±6.15; t=-7.43, P<0.001, d=1.05), indicating additional competency gains beyond traditional instruction (Table 3).

Table 3. Comparison of secondary outcome measures between the two groups (scores, mean ± SD)

Indicator	Group	Pre-test (mean ± SD)	Post-test (mean ± SD)	Improvement (mean ± SD)	Paired t-value	P-value	Within-group Cohen's d
Self-directed learning	Ward 1	65.44±5.14	70.02±4.01	4.58±2.37	-19.32	<0.001	1.93
Self-directed learning	Ward 2	65.96±4.93	82.65±3.09	16.69±6.20	-27.05	<0.001	2.69
Critical thinking	Ward 1	160.47±22.40	208.35±9.21	47.88±22.51	-21.27	<0.001	2.13
Critical thinking	Ward 2	162.30±22.14	255.72±11.32	93.42±25.95	-36.18	<0.001	3.60
Learning engagement	Ward 1	59.94±5.80	67.49±4.28	7.55±3.67	-20.56	<0.001	2.06
Learning engagement	Ward 2	60.32±5.45	85.57±4.71	25.26±7.72	-32.86	<0.001	3.27
CFRPS	Ward 1	27.90±5.82	42.98±3.36	15.08±6.15	-24.50	<0.001	2.45
CFRPS	Ward 2	28.63±5.87	50.43±3.23	21.79±6.64	-32.99	<0.001	3.28

3.3.1. Between-group Comparison of Improvement Magnitude

Table 4. Between-group comparison of improvement magnitude in secondary outcomes between the two groups (scores, mean ± SD)

Indicator	Ward 1(n=100)	Ward 2(n=101)	t-value	P-value	Cohen's d [95%CI]
Self-directed learning	4.58±2.37	16.69±6.20	-18.32	<0.001	2.57
Critical thinking	47.88±22.51	93.42±25.95	-13.30	<0.001	1.87
Learning engagement	7.55±3.67	25.26±7.72	-20.79	<0.001	2.92
CFRPS	15.08±6.15	21.79±6.64	-7.43	<0.001	1.05

3.3.2. Between-group Comparison of Post-test Scores and ANCOVA Results

Table 5. Between-group comparison of post-test scores between the two groups (scores, mean ± SD)

Indicator	Ward 1 post-test	Ward 2 post-test	t-value	Cohen's d [95%CI]	ANCOVA F-value	Adjusted difference (post-test mean difference after ANCOVA)
Self-directed learning	70.02±4.01	82.65±3.09	-25.02	3.53 [3.09,3.98]	764.44**	12.47
Critical thinking	208.35±9.21	255.72±11.32	-32.56	4.59 [4.06,5.12]	1059.93**	47.35
Learning engagement	67.49±4.28	85.57±4.71	-28.49	4.02 [3.54,4.50]	886.48**	17.99
CFRPS	42.98±3.36	50.43±3.23	-16.01	2.26 [1.91,2.61]	256.34**	7.40

Note: ANCOVA used post-test scores as the dependent variable, pre-test scores as the covariate, and group as the fixed factor; all F-values were significant at P<0.001 (**). After adjustment, between-group differences in post-test scores remained significant, confirming their robustness.

3.4. Comparison of Teaching Satisfaction

Teaching satisfaction in Ward 2 (168.43±6.58) was significantly higher than in Ward 1 (153.29±6.01) (t=-17.04, P<0.001; Cohen's d=2.40 [2.04–2.77]), a very large effect (Table 6).

Table 6. Comparison of teaching satisfaction between the two groups (scores, mean ± SD)

Group	n	Teaching satisfaction (mean ± SD)	t-value	P-value	Cohen's d [95%CI]
Ward 1	100	153.29±6.01	-17.04	<0.001	2.40 [2.04, 2.77]
Ward 2	101	168.43±6.58			

3.5. Correlation Analysis

Theoretical examination scores were significantly positively correlated with skills examination scores (r=0.61), critical thinking (r=0.46), learning engagement (r=0.43), self-directed learning (r=0.37), clinical practice readiness (r=0.33), and teaching satisfaction (r=0.29) (all P<0.001), with the strongest correlations for skills scores and critical thinking (Table 7).

Table 7. Correlation analysis between theoretical examination scores and improvement magnitudes of each scale (r values)

Variable (post-test)	Correlation with theoretical examination scores (r)	P-value
Skills examination score	0.61	<0.001
Critical thinking ability	0.46	<0.001
Learning engagement	0.43	<0.001
Self-directed learning ability	0.37	<0.001
CFRPS	0.33	<0.001
Teaching satisfaction	0.29	<0.001

Table 8. Correlation analysis between teaching satisfaction and improvement magnitudes of each scale (r values)

Item	r value	P-value
Satisfaction × Self-directed learning improvement	0.64	<0.001
Satisfaction × Critical thinking improvement	0.53	<0.001
Satisfaction × Learning engagement improvement	0.61	<0.001
Satisfaction × CFRPS (Clinical Practice Readiness) improvement	0.38	<0.001

3.6. Multiple Linear Regression Analysis of Factors Influencing Theoretical Examination Scores

With theoretical examination scores as the dependent variable, skills examination scores, post-test critical thinking, post-test learning engagement, teaching satisfaction, and post-test clinical practice readiness were entered using the enter method. The model was significant ($F(5,195)=31.05$, $P<0.001$; adjusted $R^2=0.429$), explaining 42.9% of the variance. Skills examination scores (β=0.505, P<0.001) and critical thinking (β=0.280, P=0.012) were independent predictors, whereas learning engagement (β=0.052, P=0.615), teaching satisfaction (β=-0.082, P=0.294), and clinical practice readiness (β=0.016, P=0.831) were no longer significant. Variance inflation factors ranged from 1.17 to 4.29 (all <5), indicating no severe multicollinearity (Table 9).

Table 9. Multiple linear regression analysis of factors influencing theoretical examination scores

Variable	Unstandardized coefficient B	Standard error (SE)	Standardized coefficient β	t-value	P-value	Variance inflation factor (VIF)
(Constant)	-256.450	36.699	—	-6.99	<0.001	—
Skills examination score	3.455	0.395	0.505	8.75	<0.001	1.17
Critical thinking (post-test)	0.124	0.049	0.280	2.54	0.012	4.29
Learning engagement (post-test)	0.058	0.116	0.052	0.50	0.615	3.68
Teaching satisfaction	-0.096	0.091	-0.082	-1.05	0.294	2.16
CFRPS (post-test)	0.037	0.171	0.016	0.21	0.831	1.95

Regression equation: Theoretical score = −256.450 + 3.455 × (skills score) + 0.124 × (post-test critical thinking) + 0.058 × (post-test learning engagement) − 0.096 × (teaching satisfaction) + 0.037 × (post-test CFRPS). R^2=0.443, adjusted R^2=0.429, F(5,195)=31.05, P<0.001.

3.7. Multiple Comparison Correction (FDR)

After Benjamini–Hochberg FDR correction of the four secondary-outcome comparisons, adjusted P-values for self-directed learning, critical thinking, learning engagement, and clinical practice readiness all remained <0.001, leaving the conclusions unchanged and indicating that the differences were not attributable to multiple comparisons.

Table 10. Multiple comparison correction for secondary outcome measures

Secondary outcome	Raw P-value	FDR-adjusted P-value	Remained significant?
Self-directed learning (post-test)	<0.001	<0.001	Yes
Critical thinking (post-test)	<0.001	<0.001	Yes
Learning engagement (post-test)	<0.001	<0.001	Yes
CFRPS (post-test)	<0.001	<0.001	Yes

4. Discussion

4.1. The Blended Online-to-Offline Teaching Significantly Improved Educational Achievement

Theoretical and practical skills examinations were used to assess educational achievement. The blended online-to-offline model based on the CDIO framework effectively enhanced interns' mastery of theoretical knowledge and practical skills, consistent with the findings of Fan Lu et al. [30,31].

From the perspective of Kolb's experiential learning theory, this improvement can be attributed to the complete implementation of the four-stage learning cycle—concrete experience, reflective observation, abstract conceptualization, and active experimentation [32].In the "concrete experience" phase, online theoretical modules and standardized procedural videos overcame the instructor-dependent variability of traditional preceptorship, ensured uniform content, and allowed repeated review at each student's own pace, addressing the deficiency of systematic theoretical instruction in clinical teaching [33,34].The "reflective observation" phase permeated the whole process: guided reflective questions prompted students to link theory with practice before entering clinical settings and provided a cognitive framework for subsequent learning [35].In the "abstract conceptualization" phase, group work on nursing assessment, diagnosis, and care-plan design helped students synthesize discrete knowledge into systematic nursing protocols [36].In the "active experimentation" phase, students tested their plans in simulated scenarios; Dante et al. [37] similarly found that high-fidelity simulation grounded in Kolb's theory enhanced students' ability to apply theory to practice.This cyclical progression produced a spiral ascent in learning outcomes, corroborated by regression analysis identifying skills examination scores (β=0.505, P<0.001) and critical thinking (β=0.280, P=0.012) as independent predictors of theoretical scores.Notably, infusion pump operation showed the largest effect size among the three skills whereas electrocardiographic monitoring showed a smaller one.This discrepancy may reflect differential cognitive engagement in the "active experimentation" phase: infusion pump operation involves parameter setting and dose calculation and thus demands greater cognitive processing, rendering the CDIO "Design–Implement" phases more influential, whereas electrocardiographic monitoring follows a relatively fixed sequence with lower cognitive load.This suggests that differentiated strategies should be adopted according to the characteristics of different clinical skills.

4.2. The Blended Online-to-Offline Teaching Effectively Enhanced Nursing Interns' Self-Directed Learning Ability and Clinical Thinking Ability

4.2.1. Self-Directed Learning Ability Was Significantly Improved

Among the four dimensions of self-directed learning, "learning motivation" improved most after the intervention, indicating a pronounced effect on students' intrinsic learning motivation.

At the theoretical level, integrating the CDIO framework with experiential learning theory provides a robust foundation for cultivating self-directed learning.Kolb's theory holds that learning is "the process whereby knowledge is created through the transformation of experience," encompassing concrete experience, reflective observation, abstract conceptualization, and active experimentation [32,38].Here, the online platform supplied theoretical content and standardized videos (concrete experience); offline CDIO-oriented practice required students to reflect on their performance and propose improvement plans (reflective observation and abstract conceptualization); and hands-on practice and assessment enabled internalization and application (active experimentation), forming a complete experiential learning loop. Students thus moved from "passive knowledge reception" to "active knowledge construction," the core mechanism underlying self-directed learning [39]. Round-the-clock platform access further removed the temporal and spatial constraints of traditional teaching and let students arrange content and pace autonomously—an autonomy that itself exercised self-directed learning [40].

4.2.2. Clinical Thinking Ability Was Effectively Promoted

The experimental group's post-test mean exceeded the threshold for a positive critical thinking disposition, indicating that the interns as a whole developed a positive inclination. Among the seven dimensions, "truth-seeking" showed the largest effect size, suggesting that the model best cultivated a disposition toward inquiry, whereas "cognitive maturity" showed the smallest, implying that cognitive maturity requires longer cultivation.

The CDIO framework emphasizes systematic engineering thinking through "Conceive–Design–Implement–Operate," aligning closely with the "analysis–reasoning–evaluation" competencies inherent in critical thinking.Yang et al. [41] noted that CDIO guides students to actively construct knowledge and integrate theory with practice, and that its "Implement" phase lets students translate theory into clinical judgment through high-fidelity simulation—cognitively consistent with the analytical, reasoning, and evaluative capacities demanded by critical thinking.Consistent with this, the experimental group showed significantly higher post-test critical thinking scores ($P<0.001$, $d=3.60$).

In cardiology preceptorship, students confronting real cases must complete the full clinical reasoning process—from symptom recognition and nursing diagnosis to care-plan formulation and outcome evaluation—which corresponds naturally to the four CDIO phases.Online case discussions and clinical reasoning exercises, combined with instructors' guided questioning offline, effectively trained students' analytical ability and truth-seeking disposition, consistent with Sun et al. [42] in pediatric healthcare training.

Critical thinking also has significant transfer value for clinical decision-making.It was an independent predictor of theoretical examination scores ($\beta=0.280$, $P<0.001$) and showed the strongest correlation with theoretical scores among all post-test measures ($r=0.46$, $P<0.001$).Clinical teaching should therefore not be confined to transmitting knowledge and skills but should emphasize systematic training in thinking abilities [43,44], which are more transferable and enable students to judge soundly in complex, dynamic clinical situations.

4.3. The Blended Online-to-Offline Teaching Significantly Improved Nursing Interns' Learning Engagement, Clinical Practice Readiness, and Teaching Satisfaction

4.3.1. Learning Engagement was Significantly Enhanced

Among the three dimensions of learning engagement, "vigor" improved most markedly, indicating that the model effectively activated students' learning energy and resilience; "absorption" increased relatively less, suggesting room for improvement in fostering fully immersive learning states.

From the perspective of experiential learning theory, this improvement stemmed from deep activation of learners' motivation.Zhaoquan et al. [45] found that a reflective writing intervention grounded in Kolb's theory significantly enhanced nursing undergraduates' learning engagement while increasing positive and alleviating negative academic emotions, confirming that experiential learning stimulates deep motivation at both cognitive and affective levels through the complete four-stage cycle.Kolb also noted that emotional engagement is most direct in the "concrete experience" phase; the scenario-based simulations and real-case videos provided vivid, diverse contexts that more effectively stimulated curiosity and exploratory drive than traditional lectures—the underlying reason for the substantial gain in "vigor" [46,47].In the "reflective observation" and "abstract conceptualization" phases, students collaborated on care-plan design; this social interaction facilitated deeper cognitive engagement and prevented the monotony and surface-level learning that purely procedural training can produce.Xu et al. [48] confirmed that social interaction independently predicts cognitive engagement among nursing undergraduates and that collaborative interaction promotes deep information processing through mechanisms such as "connecting" and "restructuring."

Moreover, the CDIO project-driven "active experimentation" phase let students test their plans in hands-on practice.When they saw their nursing decisions implemented successfully and recognized by peers and instructors, their needs for achievement and competence were fulfilled, forming a positive cycle of "engagement–achievement–re-engagement."Bracewell et al. [49] confirmed that simulation-based teaching enhances students' sense of competence and belonging while strengthening intrinsic motivation.

4.3.2. Clinical Practice Readiness was Significantly Improved

CFRPS scores improved markedly, and "professional identity" showed the largest effect size among the four dimensions, suggesting that the model was particularly effective in shaping professional beliefs and role cognition.

This aligns with the core objective of the CDIO framework—cultivating students' ability to "creatively solve

complex problems in real-world settings"—which is precisely the essence of clinical practice readiness. Su et al. [50] showed that the core mechanism of CDIO-based teaching lies in integrating theory and practice, thereby enhancing students' ability to apply knowledge to practical problems. Educationally, the largest improvement in "professional identity" is significant: professional identity forms through a social learning process in which students directly perceive the authentic face of nursing work via "concrete experience" (role-playing and hands-on practice in simulations) [51].Clinical experience and independent practice opportunities are the most frequently cited pathways for promoting professional identity among nursing students, and White et al. [52] likewise recommended simulation and early clinical exposure.Nursing education should therefore prioritize meaningful clinical experience opportunities.

Through "reflective observation," students gradually internalized the values and meaning of nursing: experiencing that their interventions could alleviate suffering and promote recovery made nursing tangible rather than abstract, serving as both a foundation for and a catalyst of identity formation [53].Successful experiences in "active experimentation" reinforced confidence in their professional competence, while role-model sharing and interviews with exemplary nurses on the online platform provided positive guidance [54].The model was therefore effective not only at the "instrumental" level (skills preparation) but also at the "existential" level (identity formation).

4.3.3. Teaching Satisfaction was Significantly Improved

Teaching satisfaction was significantly higher in the experimental group, indicating that the blended CDIO-based model was better recognized and welcomed by interns, consistent with previous studies showing that the CDIO model enhances nursing students' teaching satisfaction [55].

From the perspective of experiential learning theory, the experimental group experienced the complete cycle of "concrete experience–reflective observation–abstract conceptualization–active experimentation," transforming students from passive recipients into active constructors of knowledge; this enhanced sense of participation and autonomy is itself a significant source of satisfaction [56].Cheng et al. found that the autonomy and participatory opportunities afforded by the experiential learning cycle were core drivers of improved satisfaction, noting that when students gain greater control over learning, intrinsic motivation and satisfaction both increase.Rich online resources provided personalized support for different learning styles and paces, while offline CDIO group collaboration and simulation enhanced multiple core competencies, including self-directed learning and humanistic care [57].When students saw their nursing plans implemented successfully in simulations and recognized by peers and instructors, their achievement motivation was activated and translated into higher satisfaction [58].

Teaching satisfaction was significantly positively correlated with improvement magnitudes in self-directed learning ($r=0.64$, $P<0.001$), critical thinking ($r=0.53$, $P<0.001$), learning engagement ($r=0.61$, $P<0.001$), and CFRPS ($r=0.38$, $P<0.001$), suggesting that satisfaction can partially account for competency gains.However, students may be satisfied with the appeal, interactivity, and organization of the teaching process, and such affective experiences do not entirely equate to substantive competency growth.Satisfaction should therefore not be the sole indicator when evaluating educational reform but should be combined with objective competency assessments.

4.4. Limitations

First, the sample came from only two cardiology wards in a single tertiary hospital.Because internship scheduling precluded individual randomization, only ward-based cluster assignment was possible; although baseline testing indicated comparability, selection bias and ward-level confounding (e.g., case mix, nursing workload) cannot be excluded, limiting external validity.Second, the cluster effect was not adjusted for, nor was propensity score matching used, which may have overestimated intervention effects.Third, only immediate post-intervention outcomes were measured; because cultivating self-directed learning and critical thinking is a long-term process, follow-up at 3 and 6 months is recommended. Fourth, all scales were self-administered at the same time point, potentially introducing common method bias; future research could incorporate multi-source data such as objective examination scores and instructor evaluations. Fifth, the internship satisfaction scale was a generic instrument which, although reliable and valid, was not designed to capture educational reform effects and thus has limited sensitivity and specificity.

5. Conclusion

A blended online-to-offline teaching model based on the CDIO framework and Kolb's experiential learning theory was applied to cardiology nursing interns' clinical preceptorship. It significantly improved educational achievement, self-directed learning, critical thinking, learning engagement, clinical practice readiness, and teaching satisfaction, with effect sizes ranging from large to very large. Compared with traditional lecture-based teaching, it conferred additional competency gains, and critical thinking and learning engagement were key predictors of theoretical examination performance. Integrating the standardization of online theoretical learning with the experiential nature of offline practice, the model provides a transferable paradigm for clinical teaching reform in cardiology nursing. Multicenter, large-sample randomized controlled trials with long-term follow-up are needed to confirm its generalizability.

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