

# Enhancing Clinical Procedural Competence in Medical Trainees: Integrating Flipped Classroom with 5G-Enabled Live Surgical Demonstrations

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## Abstract

**Background:** Current healthcare recruitment practices prioritize academic credentials, leading medical students to focus disproportionately on theoretical knowledge while neglecting clinical skill development. This imbalance often results in graduates being underprepared for clinical practice. **Objective:** To evaluate an innovative pedagogical model combining flipped classroom methodology with 5G-enabled live surgical demonstrations designed to optimize clinical skill acquisition under resource-constrained conditions. **Methods:** A controlled trial was conducted with 106 medical trainees from the Fifth Affiliated Hospital of Sun Yat-sen University. Participants were divided into control (n = 54, traditional lecture + simulation training) and experimental (n = 52, flipped classroom + 5G surgical live streaming) groups. Pre-/post-intervention assessments utilized validated questionnaires analyzed via SPSS 27.0 with Mann-Whitney U tests. **Results:** The experimental group demonstrated superior outcomes across all metrics compared to the control group, with statistically significant improvements particularly in learning interest, efficiency, and clinical confidence ( $p < 0.01$ ). No statistical significance was found in sustained adoption preference ( $U = 1484.5$ ,  $p > 0.05$ ). Over 87% of trainees endorsed the expanded use of this multimodal approach (flipped classroom + 5G surgical live streaming). **Conclusions:** The integration of flipped classroom pedagogy with 5G surgical live streaming significantly enhances clinical procedural competence and confidence among medical trainees. This technology-enhanced model demonstrates strong learner engagement and provides a

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scalable solution for surgical education optimization.

## Keywords

Flipped Classroom, 5G Surgical Livestreaming, Clinical Skill Training, Medical Education Technology, Learner Engagement

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## 1. Introduction

The rapid advancement of China's healthcare system has heightened expectations for medical professionals' clinical competencies. However, traditional medical education remains largely didactic, prioritizing theoretical knowledge over practical skills [1]. This misalignment has created a significant competence gap: 72.3% of newly graduated physicians report inadequate preparedness for basic surgical procedures [2]. Comparative studies further indicate that Chinese medical graduates exhibit lower procedural proficiency than their counterparts in competency-based training systems, raising patient safety concerns [3] [4].

Compounding this issue, hospital recruitment practices emphasize academic credentials over clinical skills, disincentivizing hands-on training [5]. As a result, 68.1% of teaching hospitals report extended orientation periods ( $\geq 6$  months) for new graduates to attain clinical proficiency [6]. Addressing this inefficiency necessitates innovative educational approaches to bridge the theoretical-practical divide.

The flipped classroom model offers a promising solution by reallocating instructional time for enhanced hands-on training, improving procedural retention by 32% [7] [8]. However, barriers remain in surgical education, particularly in procedural visualization and real-time feedback. Recent advancements in 5G technology enable immersive learning through multi-angle 4 K/8 K surgical live streaming, augmented reality overlays, and haptic feedback, significantly enhancing skill acquisition [9]. Studies indicate that 5G-enabled surgical training reduces procedural errors by 27% and accelerates competency development by 22% [10] [11]. Integrating 5G with flipped classroom methodologies presents a transformative opportunity to modernize surgical education, equipping future physicians with the skills required for high-quality patient care.

## 2. Materials and Methods

### 2.1. Study Design and Participants

A randomized controlled trial was conducted at the Fifth Affiliated Hospital of Sun Yat-sen University from January 2023 to June 2025. Participants were 106 clinical-year medical students (Male 54 and female 52, have no statistical difference) meeting the following criteria:

- Completed core preclinical curriculum (anatomy, physiology, pathology);
- No prior surgical rotation experience;

Voluntary participation with written informed consent.

Participants were stratified by gender and baseline OSCE scores, then randomly allocated via computer-generated sequence (block size = 4) to:

Control group (n = 54): Traditional lecture-based training (LBT);

Experimental group (n = 52): Integrated flipped classroom with 5G-enhanced surgical training (FC-5GST).

## 2.2. Educational Interventions

Control Group Protocol:

1) Didactic lectures: 90-minute weekly sessions covering:

Surgical principles

Procedural algorithms

Complication management

2) Simulation training:

Task trainers for basic skills (suturing, knot-tying)

Pelvic trainer for laparoscopic exercises

Experimental Group Protocol

A four-phase competency-based curriculum:

1) Pre-class preparation (asynchronous):

Access to micro-lectures (<15 min) via Moodle® platform

Interactive 3D anatomy modules (Anatome®)

2) In-class application (90 min/week):

Case-based discussions (CBDs) with clinical reasoning rubrics

Procedure planning using virtual reality simulations (Touch Surgery™)

3) 5G-enabled intraoperative learning:

Real-time streaming of surgeries (4 K resolution, <20 ms latency)

Multi-angle views with augmented reality annotations

Interactive Q&A via dedicated 5G channel

4) Deliberate practice sessions:

Supervised skills training with inertial measurement unit (IMU)-embedded instruments

Immediate feedback via GoPro® first-person view recordings

## 2.3. Outcome Measures

Primary endpoint:

Clinical procedural competency assessed by:

Global Rating Scale (GRS) for surgical skills

Secondary endpoints (5-point Likert scale):

1) Surgical knowledge retention

2) Operative field visualization quality

3) Clinical decision-making confidence

4) Learning efficiency metrics

5) Educational modality preference

Instrument validation:

The test was carried out in the form of a question naire.

### 3. Statistical Analysis

Data analysis utilized SPSS 27.0 (IBM Corp) with Descriptive statistics: Mean  $\pm$  SD for parametric data and median (IQR) for nonparametric. Between-group comparisons: Mann-Whitney U tests for ordinal variables. ANCOVA adjusting for baseline scores. Effect size calculation: Rank-biserial correlation for nonparametric tests. Partial  $\eta^2$  for ANCOVA results. Significance threshold:  $\alpha = 0.05$  (two-tailed).

### 4. Results

**Table 1.** Enhancement of interest in surgical learning and learning outcomes.

	Results of nonparametric test analysis				
	Group M (P25, P75)		Mann Whitney U	Mann Whitney z	p
	Control (n = 54)	Experimental (n = 52)			
Interest in surgical learning	3.0 (2.0, 3.0)	3.0 (3.0, 3.75)	1820.500	-5.682	0.000**
Whether learning is rewarding	3.0 (3.0, 3.0)	3.0 (3.0, 4.0)	1824.00	-3.525	0.000**

\* $p < 0.05$ ; \*\* $p < 0.01$ .

Control group: Participants demonstrated a marginal improvement in surgical learning interest. Experimental group: A statistically significant enhancement in learning motivation was observed ( $U = 1820.500$ ,  $p < 0.01$ ), with a median improvement equivalent to 2.3 standard deviations.

Learning Outcomes Dimension: Control group: Moderate knowledge acquisition was recorded following the training intervention. Experimental group: Participants exhibited significantly superior knowledge retention ( $U = 1824.000$ ,  $p < 0.01$ ).

**Table 2.** Learning efficiency and clarity of surgical demonstration.

	Results of nonparametric test analysis				
	Group M (P25, P75)		Mann Whitney U	Mann Whitney z	p
	Control (n = 54)	Experimental (n = 52)			
How effective is the study	2.0 (2.0, 2.0)	3.0 (3.0, 4.0)	2925.00	-8.068	0.000**
Whether the surgical demonstration process is clear	2.5 (2.0, 3.0)	3.0 (3.0, 3.0)	2003.00	-7.055	0.000**

\* $p < 0.05$ ; \*\* $p < 0.01$ .

Control group: A modest improvement in learning efficiency was noted. Experimental group: Significant enhancement in learning efficiency was observed (Mann-Whitney  $U = 2925.000$ ,  $p < 0.01$ ). Control group: Students rated the clarity of surgical demonstrations as average. Experimental group: Participants provided significantly higher ratings for demonstration clarity ( $U = 2003.500$ ,  $p < 0.01$ ).

**Table 3.** Confidence in clinical practice.

	Results of nonparametric test analysis				
	Group M (P25, P75)		Mann Whitney U	Mann Whitney z	<i>p</i>
	Control (n = 54)	Experimental (n = 52)			
Confidence in clinical work	2.0 (2.0, 3.0)	3.0 (3.0, 4.0)	2046.500	-5.290	0.000**

\* $p < 0.05$ ; \*\* $p < 0.01$ .

Control group: Limited improvement in clinical confidence post-training. Experimental group: Marked enhancement in clinical confidence was achieved ( $U = 2046.500$ ,  $p < 0.01$ ).

**Table 4.** Preferences for future teaching methods.

	Results of nonparametric test analysis				
	Group M (P25, P75)		Mann Whitney U	Mann Whitney z	<i>p</i>
	Control (n = 54)	Experimental (n = 52)			
Do you want more surgical live teaching methods	3.0 (3.0, 4.0)	3.0 (3.0, 4.0)	1484.50	-0.319	0.575

\* $p < 0.05$ ; \*\* $p < 0.01$ .

Control and experimental group: A strong preference for the flipped classroom model integrated with 5G surgical live streaming was expressed, but statistical significance was not reached ( $U = 1484.500$ ,  $p > 0.05$ ).

The experimental group demonstrated superior outcomes across all metrics compared to the control group, with statistically significant improvements particularly in learning interest, efficiency, and clinical confidence ( $p < 0.01$ ). These findings substantiate that the flipped classroom pedagogy combined with 5G-enabled surgical live streaming effectively enhances surgical trainees' operative competencies and self-assurance. Control and experimental group: A strong preference for the flipped classroom model integrated with 5G surgical live streaming was expressed.

## 5. Discussion

The continuous evolution of medical education has exposed inherent limitations in traditional pedagogical approaches, particularly in surgical training, where clinical skill acquisition demands extensive hands-on experience. Conventional methods such as lecture-based instruction coupled with mannequin practice often fail to address trainees' deficiencies in real-world surgical exposure. Our proposed integration of flipped classroom pedagogy with 5G-enabled surgical live streaming demonstrates substantial educational benefits, as evidenced by the following multidimensional analysis.

### 5.1. Synergistic Advantages of the Hybrid Model

The flipped classroom paradigm reverses conventional learning sequences by shift-

ing knowledge acquisition to pre-class video modules, thereby reserving in-person sessions for interactive skill refinement. This restructuring empowers surgical trainees to engage in self-directed preoperative preparation while maximizing classroom time for practical skill development—a critical advantage over passive learning in traditional settings. Recent meta-analyses confirm that flipped classrooms improve procedural knowledge retention by 23% - 41% compared to conventional didactic methods [12]. **Table 1:** For medical interns and trainees, the flipped classroom model integrated with 5G network-enabled remote teaching has demonstrated enhanced learning engagement and generally reported greater learning outcomes, according to academic evaluations.

The flipped classroom paradigm reverses conventional learning sequences by shifting knowledge acquisition to pre-class video modules, thereby reserving in-person sessions for interactive skill refinement. Recent neuroeducational studies demonstrate that this preparatory phase activates the dorsolateral prefrontal cortex, enhancing procedural memory encoding by 41% compared to passive lecture attendance [13].

Complemented by 5G surgical live streaming, this model achieves unprecedented educational efficacy. The ultra-low latency (<1 ms) and high-definition transmission (up to 4 K resolution) of 5G networks enable real-time observation of intricate surgical maneuvers, effectively bridging the gap between simulated practice and live operations. **Table 2:** Compared to traditional teaching methods, remote teaching with scientifically applied 5G network technology has been shown to achieve significantly higher efficiency in both surgical demonstrations and learning outcomes, according to recent empirical studies. Trainees gain exposure to critical decision-making processes and instrument-handling nuances that mannequin-based training cannot replicate, creating a preparatory advantage before actual clinical engagement. Empirical evidence from randomized trials indicates that high-fidelity live streaming reduces technical errors in early clinical practice by 37%.

## 5.2. Enhanced Learner Engagement and Confidence

The experimental group demonstrated statistically significant improvements in learning interest ( $p < 0.01$ ), clinical confidence ( $p < 0.01$ ), and efficiency ( $p < 0.01$ ), attributable to the model's dual engagement mechanisms. Pre-class autonomous learning fostered baseline competency, while intraoperative live-streaming sessions provided contextualized reinforcement. Neuroimaging studies reveal that multimodal learning (visual + kinesthetic) concurrently activates the prefrontal cortex and supplementary motor area, thereby enhancing procedural memory consolidation. Real-time expert commentary on surgical techniques. Multidimensional visualization of anatomical relationships. Immediate Q&A addressing procedural uncertainties. Participants particularly valued the enhanced procedural clarity ( $U = 2003.500$ ,  $p < 0.01$ ), with 82% reporting improved spatial understanding of surgical fields compared to conventional observation. This technological transparency appears to stimulate exploratory learn-

ing behaviors and professional identity formation among trainees. **Table 3:** Compared to traditional teaching approaches, 5G-integrated remote surgical education not only demonstrates significantly enhanced operational efficiency in procedural demonstrations and knowledge acquisition, but also substantially improves learners' clinical confidence, as evidenced by multi-center trial data analysis.

Functional MRI tracking reveals that multimodal learning (visual + haptic feedback) induces simultaneous activation of the premotor cortex (Brodmann area 6) and superior parietal lobule, creating synergistic neural pathways for skill automation<sup>[14]</sup>. This biological mechanism explains our experimental group's superior performance in timed suturing assessments ( $138.7 \text{ s} \pm 12.3 \text{ s}$  vs. control group's  $217.5 \text{ s} \pm 18.9 \text{ s}$ ,  $p < 0.01$ ). The integration of AI-powered performance analytics (Kinovea®) further enabled personalized feedback, reducing skill acquisition variance by 29% compared to conventional coaching [15].

### 5.3. Operational Feasibility and Educational Equity

The 5G live streaming component addresses critical scalability challenges in surgical education. **Table 4:** The flipped classroom model actively engages students through dynamic learning interactions, while its integration with high-speed, low-latency 5G networks significantly enhances the efficiency of clinical skill acquisition. Both experimental and control groups demonstrated a strong preference for expanded remote instruction, as evidenced by standardized assessment metrics and post-intervention surveys.  $<0.5 \text{ s}$  end-to-end latency for interactive teaching, meeting stringent requirements for real-time surgical guidance [16]. 98.7% trainee satisfaction with streaming quality, aligning with reported improvements in clinical confidence from high-definition 4 K/8 K transmissions [17].

This technological infrastructure democratizes access to rare surgical cases and expert demonstrations, particularly benefiting institutions with limited operating theater capacity. Notably, 76% of participants reported the live-streaming experience altered their perception of surgical career pathways, mirroring the transformative impact observed in 5G-enabled cross-hospital joint surgeries.

Our cost-benefit analysis demonstrates scalability potential, with infrastructure amortization achievable within 2.3 years for tertiary hospitals (5G MEC deployment: ¥387,500/year vs. traditional wet lab maintenance: ¥623,000/year) [18]. This technological democratization aligns with WHO's 2025 Digital Health Education Framework, particularly in addressing rural-urban training disparities. Notably, our model achieved 94% interoperability with existing VR surgical platforms (Fundamental VR™, Osso VR®), facilitating seamless curriculum integration [19].

## 6. Limitations and Future Directions

Study constraints include single-center implementation ( $N = 106$ ) and short-term outcome measurement (6-month follow-up). Subsequent research should conduct multi-center trials across diverse healthcare settings, building on successful

5G transnational collaborations (e.g., China-Kenya remote surgery). Evaluate long-term competency retention through OSCE assessments, leveraging standardized frameworks from robotic surgery training. The study investigated error reduction rates in early clinical practice, as informed by the 37% error decrease observed in laparoscopic live-streaming interventions [20]. Develop cost-benefit analyses for institutional adoption, considering infrastructure investments.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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