

The Impact of Micro Learning on Physiology Education in First Professional MBBS Students: A Comparative Study

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Abstract

Background: Traditional teaching methods in medical education often overwhelm first-year MBBS students with vast amounts of complex physiological information. Micro learning, which delivers content in focused 3-10-minute modules, has emerged as a promising alternative pedagogical approach. **Objective:** To evaluate and compare the impact of micro learning interventions versus traditional teaching on formative and summative assessment performance in cardiovascular physiology, neurophysiology, and nerve-muscle physiology among first professional MBBS students. **Methods:** This retrospective comparative study included 792 first-year MBBS students from six consecutive batches (2019-2024) at Burdwan Medical College, West Bengal. The Intervention Group (n=396, batches 2019-2021) received micro learning modules alongside traditional teaching, while the Control Group (n=396, batches 2022-2024) received only traditional teaching. Academic performance was assessed through formative and summative examinations across three physiological domains. **Results:** The Intervention Group demonstrated significantly superior performance across all outcomes. Mean formative assessment scores were $72.4 \pm 8.6\%$ versus $64.8 \pm 9.2\%$ ($p < 0.001$, Cohen's $d = 0.85$), and summative scores were $68.5 \pm 10.2\%$ versus $61.3 \pm 11.4\%$ ($p < 0.001$, Cohen's $d = 0.66$). Overall pass rates improved from 82.7% to 91.2% ($p < 0.001$, OR=2.20). Cardiovascular physiology showed the largest effect size (Cohen's $d = 0.89$). Student and faculty feedback strongly favored the micro learning approach, with 92.7% of students recommending its continuation. **Conclusion:** Micro learning significantly enhances physiology education outcomes for first-year MBBS students. The intervention improved both formative and summative performance while reducing study time and increasing engagement. A blended approach combining micro learning with traditional teaching is recommended for optimal results.

Keywords: Micro learning, medical education, physiology, MBBS, educational technology, blended learning

Introduction

The transition from preclinical to clinical medical education represents one of the most challenging phases in a medical student's journey. First-year MBBS students face the formidable task of mastering vast amounts of complex physiological concepts that form the foundation of clinical medicine. Physiology education requires understanding intricate processes such as cardiac cycle dynamics, neural transmission mechanisms, and muscle contraction physiology—topics that demand both memorization and conceptual integration.^[1-2]

Traditional teaching methods, predominantly featuring lengthy lectures and extensive textbook reading, have remained largely unchanged for decades. However, these approaches frequently overwhelm students, leading to superficial learning, cognitive overload, and high failure rates. The passive nature of traditional lectures often fails to engage digital-native students accustomed to interactive, on-demand content consumption.^[2-7]

In recent years, microlearning has emerged as a promising pedagogical innovation that addresses many limitations of traditional methods. Microlearning is an educational strategy that delivers content in small, specific bursts, typically ranging from 3 to 10 minutes per session. Each module focuses on a single learning objective, allowing students to absorb and retain information more effectively. This approach aligns with established cognitive science principles, particularly working memory limitations and the benefits of spaced repetition.^[2-7]

The theoretical foundation for microlearning effectiveness rests on several well-established principles. Cognitive Load Theory suggests that breaking information into smaller chunks reduces extraneous cognitive load, allowing learners to dedicate more mental resources to understanding and integrating new concepts. The Spacing Effect demonstrates that distributed learning over time enhances long-term retention compared to massed practice. Additionally, microlearning naturally promotes active learning through interactive elements, quizzes, and multimedia presentations that engage multiple sensory modalities.^[5-18]

Despite growing interest in microlearning, rigorous comparative studies examining its effectiveness in medical education remain limited. Most existing research consists of small-scale pilot studies or anecdotal reports rather than comprehensive evaluations with adequate sample sizes and control groups. Furthermore, few studies have examined microlearning's impact across multiple physiological domains or investigated whether benefits extend beyond immediate knowledge acquisition to summative examination performance.^[8-18]

This study addresses these gaps by conducting a comprehensive retrospective comparison of microlearning versus traditional teaching approaches in physiology education. By examining six consecutive batches of first-year MBBS students, we aimed to determine whether microlearning produces measurable improvements in academic outcomes and whether such improvements remain consistent across different physiological topics and student cohorts.

Methodology

Study Design and Setting

This retrospective comparative observational study was conducted in the Department of Physiology at Burdwan Medical College, West Bengal, India. The study analyzed academic performance data from six consecutive MBBS batches spanning academic years 2019-2024. Data collection occurred during September-October 2025.

Study Groups

Students were divided into two groups based on their year of enrolment:

Intervention Group (Microlearning Group): This group comprised 396 students from batches 2019, 2020, and 2021. These students received teaching sessions as prescribed by the National Medical Council (NMC) curriculum, supplemented with microlearning modules covering cardiovascular physiology, neurophysiology, and nerve-muscle physiology. IEC was taken before the conduction of the intervention (BMC/ Ethics/020, 2020; BMC/I.E.C./10;2021; BMC/I.E.C./248;2021)

Control Group (Traditional Teaching Group): This group included 396 students from batches 2022, 2023, and 2024. These students received only teaching methods following the NMC curriculum without microlearning interventions.

Micro learning Intervention

The microlearning intervention consisted of short, focused digital modules delivered through a learning management system. Each module was 5-10 minutes in duration and addressed a specific learning objective within the three target physiological domains. Modules incorporated multiple formats, including video lectures, animated demonstrations of physiological processes, interactive quizzes with immediate feedback, digital flashcards for key concepts, and brief case-based scenarios applying physiological principles to clinical contexts.

Students could access modules on demand via mobile devices or computers, allowing flexible learning aligned with individual schedules. The platform tracked usage metrics, including module completion rates, time spent, quiz performance, and revision patterns.

Sample Size and Participants

The total sample comprised 792 students (approximately 132 per batch across six batches). Sample size calculations for independent two-group comparisons assumed an expected medium-to-large effect size (Cohen's $d=0.5$), 80% power, and 0.05 significance level, requiring a minimum of 406 students per group.

Inclusion criteria required students who: (1) were enrolled in batches 2019-2024; (2) completed both formative and summative assessments in all three physiological domains; (3) maintained attendance $\geq 75\%$; and (4) had accessible academic records.

Exclusion criteria eliminated students who: (1) discontinued or took leave during the first professional year; (2) were absent from any formative or summative assessment; (3) had incomplete academic records; (4) repeated the first professional year; or (5) received special accommodations significantly altering the assessment format.

Study Variables and Outcome Measures

Primary Outcomes:

- Formative assessment scores (percentage) in cardiovascular physiology, neurophysiology, and nerve-muscle physiology
- Summative assessment scores (percentage) in the three physiological domains
- Effect sizes of microlearning intervention across topics

Secondary Outcomes:

- Domain-specific intervention benefits
- Correlation between formative and summative performance
- Retention rates (formative-summative score gaps)
- Gender-based differences in response
- Pass percentages ($\geq 50\%$ threshold) and grade distributions
- Year-to-year consistency in outcomes

Data Collection

Academic performance data were extracted from departmental records, university examination records from the Dean's office, attendance registers, admission records, and internal assessment documentation. Both groups were matched on baseline characteristics, including gender distribution, 12th standard PCB (Physics-Chemistry-Biology) percentage.

Feedback data were collected through structured surveys administered to students (response rate 89.4% for Intervention Group, 86.9% for Control Group) and faculty interviews (100% response rate, $n=12$). surveys employed 5-point Likert scales and open-ended questions assessing satisfaction, perceived benefits, challenges, and preferences.

Statistical Analysis

Continuous variables were expressed as mean $\pm$ standard deviation and compared using independent samples t-tests. Categorical variables were analyzed using chi-square tests. Effect sizes were calculated using Cohen's d, with values of 0.2, 0.5, and 0.8 representing small, medium, and large effects, respectively. Pass rate comparisons were conducted using chi-square tests with odds ratios and 95% confidence intervals. Statistical significance was set at $p < 0.05$. All analyses were performed, ensuring assumptions for parametric tests were satisfied.

Results

Sample Characteristics

A total of 792 first-year MBBS students met the inclusion criteria and were included in the final analysis. Both groups were comparable in baseline characteristics, with no statistically significant differences in gender distribution, 12th standard PCB percentage (all $p > 0.05$), confirming successful matching of groups.

Primary Outcome: Formative Assessment Performance

Students in the Intervention Group demonstrated significantly superior formative assessment performance across all three physiological domains (Table 1). The overall mean formative score for the microlearning group was $72.4 \pm 8.6\%$ compared to $64.8 \pm 9.2\%$ in the control group ($p < 0.001$, Cohen's $d = 0.85$), representing a large effect size.

The comparative analysis between the intervention and control groups demonstrated consistently higher academic performance among students who participated in the structured intervention program. In the formative assessments, the intervention group achieved significantly better scores across cardiovascular, neurophysiology, and nerve-muscle physiology topics, with mean differences ranging from 6.5% to 8.4% and large effect sizes (Cohen's $d = 0.73-0.89$). Similarly, in summative assessments, the intervention group continued to outperform the control group by 7.1% to 7.4% across all topics, with moderate-to-large effect sizes (Cohen's $d = 0.61-0.69$).

Pass rate analysis revealed a higher overall success rate in the intervention group (91.2%) compared to the control group (82.7%), with a statistically significant difference ($p < 0.001$) and more than double the odds of passing ($OR = 2.20$). Moreover, a greater proportion of students in the intervention group attained excellent grades (28.5% vs. 16.4%), while fewer failed (8.1% vs. 17.2%), indicating enhanced mastery and reduced academic failures.

Learning retention analysis showed that both groups maintained similar retention rates (94.6%), though the intervention group sustained higher absolute performance levels in both formative and summative assessments. Gender-based comparisons revealed that female students outperformed males in both groups, with the intervention females scoring slightly higher in both formative (72.9%) and summative (69.2%) assessments. Overall, the intervention strategy significantly improved academic performance, grade distribution, and pass rates without compromising knowledge retention across genders. (Table 2-3)

The data demonstrates substantial superiority of the microlearning intervention across multiple dimensions. Table 4 reveals consistently higher satisfaction scores in the intervention group across all parameters, with differences ranging from 0.74 to 1.10 points on a 5-point scale (all $p < 0.001$). Most notably, students found learning more engaging (4.41 vs 3.31) and appreciated the self-paced learning flexibility (4.38 vs 3.22).

Interestingly, the intervention group required less self-study time (78.6 vs 92.4 minutes daily), suggesting improved learning efficiency rather than increased time investment. This challenges the assumption that better performance requires more study hours, indicating that the pedagogical approach matters more than duration.

Table 5 demonstrates remarkable consistency across three intervention batches (2019-2021), with formative scores clustering around 72% and summative scores near 68%, alongside consistently high pass rates (90-92%). The control group batches (2022-2024) showed similar internal consistency but at lower performance levels (approximately 64-65% formative, 61% summative, 82-83% pass rates). This temporal consistency strengthens causal attribution to the intervention rather than cohort-specific factors.

Faculty endorsement strongly favored microlearning (4.43 vs 3.46 rating; 91.7% vs 41.7% recommending continuation), validating both student satisfaction and performance outcomes from an educator perspective. Critically, despite the intervention's success, most students (69.1%) and faculty (75%) preferred a blended approach rather than exclusive microlearning implementation. This pragmatic finding suggests microlearning works best as a complementary strategy integrated with traditional methods, rather than a complete replacement, acknowledging the continued value of conventional pedagogical elements in medical education.

Discussion

This comprehensive study provides compelling evidence for the effectiveness of microlearning in physiology education for first professional MBBS students. The Intervention Group demonstrated consistent and statistically significant improvements across all measured outcomes, with a 7.6 percentage point advantage in formative assessments and 7.2 percentage points in summative assessments. The large effect sizes (Cohen's d ranging from 0.61 to 0.89) suggest that microlearning offers more than marginal gains—it represents a meaningful enhancement to traditional teaching methods. The improvement in pass rates deserves particular attention. Students exposed to microlearning were 2.20 times more likely to pass overall assessments, with failure rates nearly halved (8.1% vs 17.2%). From both educational and institutional perspectives, this reduction in academic failure has profound implications, representing not only individual student achievement but also more efficient use of educational resources and potentially better-prepared future physicians.

The study's results align well with established cognitive psychology principles. Cognitive Load Theory suggests that breaking information into smaller, focused units reduces extraneous cognitive load, allowing students to dedicate more working memory resources to processing and understanding physiological concepts. The finding that Intervention Group students achieved superior results with less daily self-

study time (78.6 versus 92.4 minutes) indicates more efficient learning—a hallmark of reduced cognitive load.^[19-24]

A review by De Gagne et al., published in JMIR Medical Education in 2019, examined microlearning in health professions education. Microlearning involves acquiring knowledge or skills in small units and has been endorsed by health educators for student learning, training, and continuing education. From 3,096 references retrieved, 17 articles published between 2011 and 2018 met the inclusion criteria. These studies came from various countries including the United States, China, India, Australia, Canada, Iran, Netherlands, Taiwan, and the United Kingdom, and covered diverse health disciplines such as medicine, nursing, pharmacy, dentistry, and allied health. The studies used various technologies including podcasts, short messaging services, microblogging, and social networking. Based on established microlearning criteria, each study satisfied at least 40% of the characteristics, with all studies featuring content that took less than 15 minutes to complete and utilized content aggregation. When evaluated using the Kirkpatrick model, 94% of studies assessed student reactions (level 1), 82% evaluated knowledge or skill acquisition (level 2), 29% measured effects on student behavior (level 3), and no studies examined the highest level of outcomes. Microlearning demonstrated positive effects on students' knowledge, confidence in performing procedures, knowledge retention, and engagement in collaborative learning. The strategy proved particularly useful as a refresher for infrequently performed skills or when learning new procedures, potentially improving clinical safety. However, the review identified downsides, including pedagogical discomfort, technology inequalities, and privacy concerns.^[23]

Cognitive Load Theory (CLT) has been foundational in instructional design and educational psychology for decades, focusing on how learners' cognitive architecture (especially working memory limitations) interacts with instructional materials. Key thematic clusters include: (1) **Presentation and handling of learning materials:** Studies revisit classic effects such as split-attention (separate sources increasing load) and redundancy (multiple representations hindering or helping learning), but examine them with new tools (e.g., mixed reality). (2) **Monitoring and self-regulation:** As online and automated learning proliferate, issues of self-monitoring, emotional regulation, and learner control become central. For example, cognitive reappraisal is discussed as a strategy to reduce the emotional burden that may increase cognitive load. (3) **Working memory recovery and replenishment:** With information overload increasing, interventions to restore cognitive capacity (e.g., nature exposure) are introduced, though rigorous effects remain under investigation. (4) **Individual learner characteristics:** Interest, prior knowledge, spatial ability, working memory capacity and goal orientation are shown to moderate how cognitive load impacts learning. Tailoring design to learners' capabilities becomes vital. Finally, (5) **Embodied learning:** Integrating physical, bodily interaction (via augmented reality

or motor tasks) is gaining traction as a way to reduce cognitive load and leverage human cognitive architecture. [19-25]

The modular nature of microlearning naturally promotes the Spacing Effect, with students accessing modules an average of 3-4 times for revision, creating distributed practice opportunities that strengthen long-term memory consolidation. The 94.6% retention rate from formative to summative assessments in both groups, occurring at different performance levels, suggests that the Intervention Group's superior initial encoding translated into superior long-term retention at higher absolute performance levels.

High engagement metrics (>89% module completion rates) and strong student satisfaction scores (4.31 vs 3.40) indicate that microlearning successfully transforms passive information reception into active knowledge construction. This shift from passive to active learning likely contributed significantly to observed improvements. Cardiovascular physiology showed the largest effect size (Cohen's $d=0.89$), raising interesting questions about which physiological domains benefit most from microlearning. Cardiovascular physiology involves numerous interconnected concepts—cardiac cycle, hemodynamics, electrical conduction, pressure regulation—that may be particularly amenable to modular breakdown. The ability to isolate specific mechanisms (such as Frank-Starling relationship or baroreceptor reflexes) into discrete learning units may have facilitated deeper understanding.

The slightly lower (though still substantial) effect size in nerve-muscle physiology (Cohen's $d=0.73$) might reflect the more linear, sequential nature of this content. Muscle contraction mechanisms follow a relatively straightforward sequence from neural stimulation to sarcomere shortening, which may be effectively taught through traditional methods as well as microlearning.

Perhaps the study's most important insight emerges from feedback analysis: the overwhelming preference (69.1% of students, 75.0% of faculty) for a blended approach combining microlearning with traditional teaching. These findings challenge false dichotomies that pit traditional against innovative pedagogies. The reality of effective medical education lies in thoughtful integration.

Microlearning excels at introducing foundational concepts, providing flexible review opportunities, and offering just-in-time knowledge refreshers. Traditional face-to-face teaching remains valuable for facilitating discussion, addressing complex questions, providing clinical context, and building student-faculty relationships. The "flipped classroom" model emerges as a natural integration strategy, where students engage with microlearning modules before class to build foundational knowledge, freeing classroom time for higher-order activities such as problem-solving, clinical correlation, and peer discussion. [19-29]

The study acknowledges important implementation challenges. Technical issues affected 22.6% of Intervention Group students, highlighting the digital divide concern. Faculty feedback revealed that microlearning required substantial initial time investment (45.6 hours per topic), though annual workload decreased by approximately 15 hours per topic after the first year due to module reusability.

The 100% faculty endorsement for institutional support and 91.7% for training workshops indicates clear needs that institutions must address. Without adequate infrastructure for content creation, quality assurance, and technical support, even enthusiastic faculty may struggle to develop effective micro learning resources.

Quality control emerges as critical—not all brief educational content constitutes effective microlearning. Simply chopping traditional lectures into shorter segments misses the point. Effective modules require careful instructional design, clear learning objectives, appropriate assessment alignment, and multimedia elements that enhance rather than distract from learning.

The study's retrospective design and use of historical controls introduce significant limitations. Temporal separation may introduce confounding despite matching on measurable variables. Students entering medical school in 2024 have fundamentally different digital literacy and learning expectations compared to 2019 counterparts. The pandemic (affecting the 2020-2021 batch) created dramatically different educational contexts, potentially creating cohort effects unrelated to the specific micro learning intervention.

Generalizability to other contexts—different cultural settings, varying resource availability, alternative curricular structures—remains uncertain. The study was conducted at a single institution following the NMC curriculum, which may differ substantially from medical education models elsewhere. High baseline pass rates even in the Control Group (82.7%) suggest a relatively successful program overall, and institutions with different baseline performance might see different effect sizes.

Perhaps the most significant limitation is measuring only intermediate academic outcomes. The study demonstrates that microlearning improves examination scores, but the ultimate question remains unanswered: Does this translate into better clinical competence, improved patient care, or enhanced long-term retention when students enter clinical practice? Longitudinal studies tracking students through clinical rotations and residency would provide more definitive evidence of microlearning's value.

While the study touches on the digital divide, deeper consideration of equity issues is warranted. Microlearning's flexibility assumes students have reliable internet access, functional devices, and private learning spaces. Students from economically disadvantaged backgrounds may lack these resources, potentially widening achievement gaps.

Institutions implementing microlearning must proactively address these concerns through device lending programs, ensuring offline content availability, providing adequate internet infrastructure in educational facilities, and maintaining robust traditional teaching components that don't require technology access.

The study reports no significant interaction between gender and intervention effect ($p=0.542$), with both male and female students benefiting similarly. This finding, while reassuring, suggests that well-designed microlearning can be universally effective across demographic groups when implemented thoughtfully.

This study contributes to growing evidence that medical education need not be bound by traditional pedagogical approaches. The success of microlearning challenges several assumptions: that hour-long lectures represent the gold standard, that educators must "cover" all content comprehensively, and that students are passive recipients of knowledge. Instead, the study demonstrates students' capacity for active, autonomous learning when provided with appropriate tools and structure.^[22-28]

Several important questions emerge from this study. Research exploring optimal module duration and structure for different content types would inform design decisions. Investigation of personalized, adaptive learning pathways based on individual performance patterns could significantly enhance effectiveness. Studies examining how microlearning extends beyond basic sciences into clinical medicine, particularly just-in-time modules providing physiological refreshers relevant to specific clinical scenarios, could bridge the basic science-clinical practice gap.^[23-29]

Most critically, long-term retention studies following cohorts through clinical training and early practice would assess whether enhanced first-year learning translates into superior clinical reasoning and performance.^[23] Multisite validation studies across diverse institutional contexts would establish generalizability and identify factors moderating effectiveness.

Based on findings, institutions considering microlearning implementation should: (1) start with blended approaches rather than wholesale replacement of traditional teaching; (2) invest in quality development with adequate resources for instructional design support; (3) prioritize complex topics showing largest effect sizes; (4) ensure equitable access through proactive technology barrier mitigation; (5) build faculty buy-in through involvement, support, and recognition; (6) implement analytics and feedback loops for continuous improvement; (7) align assessment with pedagogy; and (8) plan for sustainability through regular content updates and knowledge sharing.

Conclusions

This study provides robust evidence that microlearning significantly enhances physiology education for first professional MBBS students when implemented as part of a comprehensive teaching strategy. The intervention produced large, consistent effect sizes across multiple batches, topics, and demographic subgroups,

demonstrating reproducibility and reliability. The overwhelming preference for blended approaches from both students (69.1%) and faculty (75.0%) provides crucial guidance—effective medical education emerges not from choosing between traditional and innovative methods, but from thoughtful integration. Microlearning excels at introducing foundational concepts and providing flexible review, while traditional teaching remains valuable for discussion, mentorship, and professional identity formation.

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Table 1: Comparison of Formative and Summative Assessment Scores between Groups

Assessment Type & Topic	Intervention Group (n=396) Mean $\pm$ SD	Control Group (n=396) Mean $\pm$ SD	Mean Difference	p-value	Cohen's d
Formative Assessments					
Cardiovascular Physiology	73.8 $\pm$ 8.4%	65.9 $\pm$ 9.1%	7.9%	<0.001	0.89
Neurophysiology	71.6 $\pm$ 9.2%	63.2 $\pm$ 10.1%	8.4%	<0.001	0.87
Nerve-Muscle Physiology	71.8 $\pm$ 8.9%	65.3 $\pm$ 8.8%	6.5%	<0.001	0.73
Overall Formative Score	72.4 $\pm$ 8.6%	64.8 $\pm$ 9.2%	7.6%	<0.001	0.85
Summative Assessments					
Cardiovascular Physiology	69.8 $\pm$ 10.1%	62.4 $\pm$ 11.2%	7.4%	<0.001	0.69
Neurophysiology	67.9 $\pm$ 11.0%	60.8 $\pm$ 12.3%	7.1%	<0.001	0.61
Nerve-Muscle Physiology	67.8 $\pm$ 9.8%	60.7 $\pm$ 10.9%	7.1%	<0.001	0.68
Overall Summative Score	68.5 $\pm$ 10.2%	61.3 $\pm$ 11.4%	7.2%	<0.001	0.66

Table 2: Pass Rates and Performance Grade Distribution

Category	Intervention Group (n=396)	Control Group (n=396)	Absolute Difference	p-value	Odds Ratio (95% CI)
Overall Pass Rates (≥50%)					
Overall Pass Rate	91.2% (361/396)	82.7% (328/396)	8.5%	<0.001	2.20 (1.58-3.06)
Performance Grade Distribution					
Excellent (≥75%)	28.5% (113/396)	16.4% (65/396)	12.1%	<0.001	-
Good (60-74%)	48.7% (193/396)	45.2% (179/396)	3.5%	0.342	-
Satisfactory (50-59%)	14.6% (58/396)	21.2% (84/396)	-6.6%	0.014	-
Fail (<50%)	8.1% (32/396)	17.2% (68/396)	-9.1%	<0.001	-

Table 3: Learning Retention and Gender-Based Analysis

Analysis Category	Group/Sub group	Mean Formative Score	Mean Summative Score	Score Difference	Retention Rate
Learning Retention					
Intervention Group	Overall	72.4 ± 8.6%	68.5 ± 10.2%	-3.9%	94.6%
Control Group	Overall	64.8 ± 9.2%	61.3 ± 11.4%	-3.5%	94.6%
Gender-Based Performance					
Male Students	Intervention	71.9 ± 8.8%	67.8 ± 10.5%	-	-
Male Students	Control	64.2 ± 9.4%	60.7 ± 11.8%	-	-
Female Students	Intervention	72.9 ± 8.4%	69.2 ± 9.8%	-	-
Female Students	Control	65.4 ± 9.0%	61.9 ± 11.0%	-	-

No significant interaction between gender and intervention effect (p=0.542)

Table 4: Student Satisfaction and Feedback Analysis

Parameter	Intervention Group (n=354) Mean $\pm$ SD	Control Group (n=344) Mean $\pm$ SD	p-value
Teaching methods were effective	4.32 $\pm$ 0.68	3.54 $\pm$ 0.82	<0.001
Content was easy to understand	4.28 $\pm$ 0.71	3.48 $\pm$ 0.79	<0.001
Learning was engaging and interesting	4.41 $\pm$ 0.64	3.31 $\pm$ 0.86	<0.001
I could learn at my own pace	4.38 $\pm$ 0.69	3.22 $\pm$ 0.91	<0.001
Concepts were easy to retain	4.25 $\pm$ 0.73	3.45 $\pm$ 0.84	<0.001
I felt confident during examinations	4.19 $\pm$ 0.76	3.38 $\pm$ 0.88	<0.001
Overall Satisfaction	4.31 $\pm$ 0.70	3.40 $\pm$ 0.85	<0.001
Average Daily Self-Study Time (minutes)	78.6 $\pm$ 42.3	92.4 $\pm$ 51.6	<0.001

Satisfaction scores: 1=Strongly Disagree, 5=Strongly Agree

Table 5: Batch-Wise Consistency and Faculty Feedback

Category	Details	Performance / Rating
Intervention Group Batch Consistency		
Batch 2019	Mean Formative / Summative / Pass Rate	71.8 $\pm$ 8.9% / 67.9 $\pm$ 10.8% / 90.2%
Batch 2020	Mean Formative / Summative / Pass Rate	72.6 $\pm$ 8.2% / 68.4 $\pm$ 9.9% / 91.7%
Batch 2021	Mean Formative / Summative / Pass Rate	72.8 $\pm$ 8.7% / 69.2 $\pm$ 9.8% / 91.9%
Control Group Batch Consistency		
Batch 2022	Mean Formative / Summative / Pass Rate	65.2 $\pm$ 9.5% / 61.8 $\pm$ 11.7% / 83.3%
Batch 2023	Mean Formative / Summative / Pass Rate	64.8 $\pm$ 9.1% / 61.2 $\pm$ 11.3% / 82.6%

Batch 2024	Mean Formative / Summative / Pass Rate	64.4±9.0% / 60.9±11.2% / 82.1%
FACULTY SATISFACTION (n=12)		
Microlearning Approach	Overall Faculty Rating (1-5 scale)	4.43 ± 0.59
Traditional Approach	Overall Faculty Rating (1-5 scale)	3.46 ± 0.73
Faculty Recommending Continuation	Microlearning / Traditional	91.7% / 41.7%
Preferred Teaching Model		
Students Preferring Blended Approach	n=698 respondents	69.1% (482/698)
Faculty Preferring Blended Approach	n=12 faculty	75.0% (9/12)