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From lectures to flipped classroom: A quasi-experimental crossover study on students' performance and perceptions in learning histology.

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ABSTRACT:

Background:
Anatomy education has traditionally relied on didactic lectures, but innovative approaches such as the flipped classroom are increasingly being explored to promote active learning, engagement, and deeper understanding.

Objective:
To evaluate the effectiveness of the flipped classroom compared to traditional lectures in teaching histology to first-year MBBS students.

Methods:
A quasi-experimental crossover study was conducted among 150 first-year MBBS students. Two histology topics (stomach and small intestine) were taught using the flipped classroom and didactic lecture methods. Pre-test, mid-test, and post-test scores were recorded using multiple-choice questionnaires. Group A initially underwent flipped classroom teaching, and Group B didactic lectures for Topic 1, followed by crossover for Topic 2. Statistical analysis was performed using paired and independent t-tests.

Results:
The participants comprised 150 first-year MBBS students (52% female; mean age 19.4 ± 0.8 years). Both teaching methods significantly improved student performance. Didactic lectures showed greater short-term gains (mean post-test = 9.48 ± 1.33 vs. 8.92 ± 1.73; $p < 0.05$). The flipped classroom group demonstrated a steady incremental improvement from pre-test (6.98 ± 1.94) to mid-test (7.25 ± 2.17) and post-test (8.92 ± 1.73), confirming progressive learning and retention ($p < 0.001$).

Conclusion:
Didactic lectures remain effective for achieving rapid short-term learning gains, whereas the flipped classroom fosters gradual improvement, learner autonomy, and deeper engagement.

Recommendations:
A blended, context-sensitive approach integrating both lectures and flipped classroom strategies is recommended to optimize learning outcomes in anatomy education. Future studies should assess long-term knowledge retention, adaptability, and the role of technology-enabled blended models across diverse medical curricula.

Keywords: *Anatomy education, Histology, Flipped classroom, Didactic lecture, medical students, Active learning, Knowledge retention, Teaching methodology*
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Introduction

The teaching of anatomy has undergone a remarkable transformation across history, evolving from early ritualistic practices to contemporary learner-centered pedagogies. In ancient Egypt and Mesopotamia (3000–1000 BC), sacrificial victims were examined, and descriptions of organs were recorded in texts like the *Ebers Papyrus*. These observations were closely tied to mummification and early medical practices. Greek medicine, guided by Hippocrates (460–370 BC), emphasized observation of the human body and natural causes of disease, though human dissection was avoided due to cultural taboos. Aristotle (384–322 BC) advanced comparative anatomy through systematic animal dissections, while the Alexandrian school, led by Herophilos and Erasistratus (around 300 BC), pioneered human dissection, particularly of the nervous and circulatory systems.

Medieval Decline:

Between the 5th and 13th centuries, human dissection declined because of religious prohibitions. During this era, Galen (129–216 CE), relying largely on animal dissections, became the authoritative source on anatomy for centuries.

Renaissance Revival and Early Modern Advances:

The Renaissance (14th–16th centuries) brought renewed interest in human cadaveric dissection. Andreas Vesalius revolutionized anatomical study by direct observation and correction of Galenic errors, while William Harvey's 17th-century discovery of blood circulation fundamentally changed physiological understanding, despite initial resistance lasting two decades [1]. The 19th century witnessed the emergence of cell theory, and by the late 19th century, standardization of anatomical terminology occurred with the *Basle Nomina Anatomica* (1895), which simplified nomenclature for teaching and research [1].

Contemporary Approaches:

With technological progress, anatomy teaching now integrates cadaveric dissection, imaging, simulations, and digital 3D models. Traditional didactic lectures, once the mainstay, are increasingly complemented or replaced by innovative methods such as the flipped classroom model. This approach allows learners to engage with recorded lectures or readings before class, while classroom sessions focus on interactive discussions, case-based problem solving, and application of theoretical knowledge [2,3].

Flipped Classroom in Anatomy Education:

Anatomy requires not only memorization but also spatial and functional understanding. The flipped classroom has been shown to enhance active participation, promote critical thinking, and improve knowledge retention compared to passive lectures [4–7]. Studies demonstrate that students in flipped settings outperform peers in traditional lectures on anatomy assessments [8,9]. A meta-analysis of 28 comparative studies involving 4715 students revealed a strong preference for flipped classrooms over teacher-centered methods [10]. Additional evidence from Indian and international studies [11–16] consistently indicates higher post-test scores, deeper engagement, and more positive perceptions among medical students exposed to flipped teaching. Furthermore, this model encourages independence, collaboration, and communication skills, though it may be time-consuming for both students and faculty [13,14].

Recent Adaptations:

The COVID-19 pandemic accelerated the adoption of hybrid and student-centered strategies within the competency-based medical education (CBME) curriculum. Modified flipped classroom methods enabled continued knowledge transfer while reducing infection risk, further validating this approach [4].

Rationale and Aim:

Given its potential to foster deeper learning, flipped classroom teaching is increasingly recognized as a promising alternative to lectures in microscopic anatomy. This study, therefore, aims to evaluate whether the flipped classroom is equally or more effective than traditional lectures in enhancing knowledge retention and conceptual understanding in anatomy.

MATERIALS AND METHODS

Study Design

This study adopted a quasi-experimental crossover design involving first-year MBBS students. A total of 150 students were enrolled and equally divided into two groups of 75 each (Group A and Group B). Two histology topics, the stomach and small intestine, were selected for instructional comparison between two teaching modalities: the flipped classroom and the traditional didactic lecture.

Group A initially underwent flipped classroom teaching for Topic 1 and subsequently attended a didactic lecture for Topic 2, whereas Group B received the reverse sequence. Each instructional session lasted approximately 90 minutes,

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consisting of a 60-minute structured teaching component followed by 30 minutes of guided discussion.
Knowledge acquisition and short-term retention were evaluated through pre-test, mid-test (for the flipped classroom only), and post-test multiple-choice question (MCQ) assessments. Statistical analysis was performed using paired t-tests for within-group comparisons and independent t-tests for between-group comparisons.

Study Setting

The study was conducted in the Department of Anatomy, Dr. B. R. Ambedkar Medical College, Bangalore, India, during the 2024 academic year. Participants were first-year MBBS students enrolled in the anatomy course. All teaching sessions were held in departmental lecture halls equipped with standard audio-visual aids.
For the flipped classroom sessions, preparatory materials, including PowerPoint presentations, relevant research articles, and textbook references, were distributed via a **dedicated WhatsApp group** one week before the class. Both the flipped and didactic sessions were conducted by the same faculty members to maintain uniformity in teaching quality and delivery.

Participants and Eligibility Criteria

The study population comprised **150 first-year MBBS students** enrolled in the anatomy course at Dr. B.R. Ambedkar Medical College, Bangalore.

Inclusion Criteria

Students are enrolled in the first year of the MBBS program.
Students who were present for the teaching sessions.
Students who provided informed consent to participate in the study.

Exclusion Criteria

Students are absent during the teaching sessions.
All eligible students were allocated into two groups (Group A and Group B, each with 75 students) using roll number-based distribution for the crossover design.

Sample Size Determination

The sample size was estimated based on detecting a moderate effect size (Cohen's $d = 0.5$) between the flipped classroom and didactic lecture groups, with a significance level (α) of 0.05 and power ($1-\beta$) of 0.80. Using these assumptions for a two-tailed independent *t*-test, the minimum required sample size was calculated to be 64 students per group (total 128 students).

To account for potential non-response or incomplete participation, the sample size was increased by approximately 15%, resulting in a required sample size of about 150 students. Conveniently, this matched the available cohort of first-year MBBS students, and therefore, the entire batch of 150 students was included in the study to maximize statistical validity.

Data Collection Tool

Data were collected using structured multiple-choice questionnaires (MCQs) designed to assess students' knowledge and understanding of the assigned histology topics. The questionnaire consisted of 20 validated MCQs for each topic, covering key concepts, structural identification, and functional correlations.

- **Pre-test (P1):** Administered before the teaching session to assess baseline knowledge.
- **Mid-test (P2):** Conducted only for the flipped classroom group at the beginning of the session to evaluate knowledge gained from pre-class preparation.
- **Post-test (P3):** Administered five days after the teaching session to assess short-term knowledge retention and understanding.

The MCQs were prepared and reviewed by subject experts from the Department of Anatomy to ensure content validity, relevance, and appropriate difficulty level. Questionnaires were distributed and responses were collected in classroom settings under faculty supervision.

Data Collection Procedure

Data were gathered in a structured, stepwise manner using pre-test, mid-test, and post-test assessments:

Grouping of Students:

A total of 150 medical students were divided into two groups according to roll numbers—Group A (1–75) and Group B (76–150).

Pre-test (P1):

Both groups completed a multiple-choice question (MCQ)-based pre-test 10 days before the scheduled session to assess baseline knowledge.

Distribution of Study Material (Flipped Classroom):

For the group allocated to flipped classroom teaching, relevant resources (PowerPoint slides, reference articles,

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Original Article

and textbook chapters) were shared via a WhatsApp group one week before the session to enable self-directed learning.

Mid-test (P2):
At the start of the flipped classroom session, students undertook a short mid-test to evaluate the effectiveness of pre-class preparation.

Classroom Session:
Flipped Classroom Group:
Randomly selected students presented or discussed the topic, followed by group discussions moderated by faculty. Each session concluded with a faculty-led summary.

Didactic Lecture Group:
The assigned faculty delivered the topic using a structured, instructor-led lecture format.

Post-test (P3):
Five days after the teaching session, both groups were assessed with a post-test (MCQ-based) on the same topic to evaluate knowledge acquisition and short-term retention.

Crossover Design:
For the second topic, the groups were interchanged: Group A received a didactic lecture while Group B received flipped classroom teaching. The same procedure of pre-test, mid-test (for flipped), and post-test was followed. All tests were conducted under faculty supervision to ensure fairness and academic integrity.

Data Analysis
Data were entered into Microsoft Excel and analyzed using SPSS software version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean ± standard deviation (SD) for continuous variables.
Within-group comparisons (pre-test vs. post-test scores) were performed using the *paired t-test*.
Between-group comparisons (flipped classroom vs. didactic lecture) were analyzed using the *independent samples t-test*. A $p\text{-value} < 0.05$ was considered statistically significant. Bar charts and line diagrams were used to visually represent score distributions and trends in knowledge gain across both teaching modalities.

Bias
To minimize bias, all first-year MBBS students from the batch were included, thereby reducing the risk of selection bias. The same faculty members conducted both the flipped classroom sessions and the didactic lectures to ensure uniformity in teaching quality and delivery, thus limiting performance bias. Assessment bias was addressed by using the same set of validated MCQs for pre-test, mid-test, and post-test evaluations, with responses collected under supervision. A crossover design was employed so that both groups were exposed to both teaching methods, reducing the influence of order effects. Additionally, students were instructed not to share test content outside the classroom to prevent information contamination between groups. However, the possibility of response bias, as students were aware of being studied, could not be eliminated.

Ethical Considerations
The study was conducted after obtaining approval from the Institutional Ethics Committee of Dr. B.R. Ambedkar Medical College, Bangalore (ECR/800/Ambedkar/Inst/KA/2024/17). Written informed consent was obtained from all participating students after explaining the purpose and procedure of the study. Participation was entirely voluntary, and students were assured that non-participation would not affect their academic standing or internal assessments. Confidentiality and anonymity of the participants were strictly maintained throughout the study, and the collected data were used solely for research purposes. The study adhered to the principles of the Declaration of Helsinki (2013 revision) for ethical conduct in research involving human participants.

Results:
Participant Flow
A total of 158 first-year MBBS students enrolled in the anatomy course were initially screened for eligibility. Of these, 150 students fulfilled the inclusion criteria and provided written informed consent. Eight students were excluded—five were absent during one or more sessions, and three did not complete the assessments.
The remaining 150 students were enrolled and randomly divided (based on roll numbers) into two equal groups of 75 students each: Group A – received the flipped classroom for Topic 1 (stomach) and a didactic lecture for Topic 2 (small intestine). Group B – received the didactic lecture for Topic 1 and the flipped classroom for Topic 2. All participants completed their allocated interventions and assessment tests (pre-, mid-, and post-tests as applicable). No participant

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withdrawals occurred after enrollment, ensuring a 100 % completion rate for the crossover design.

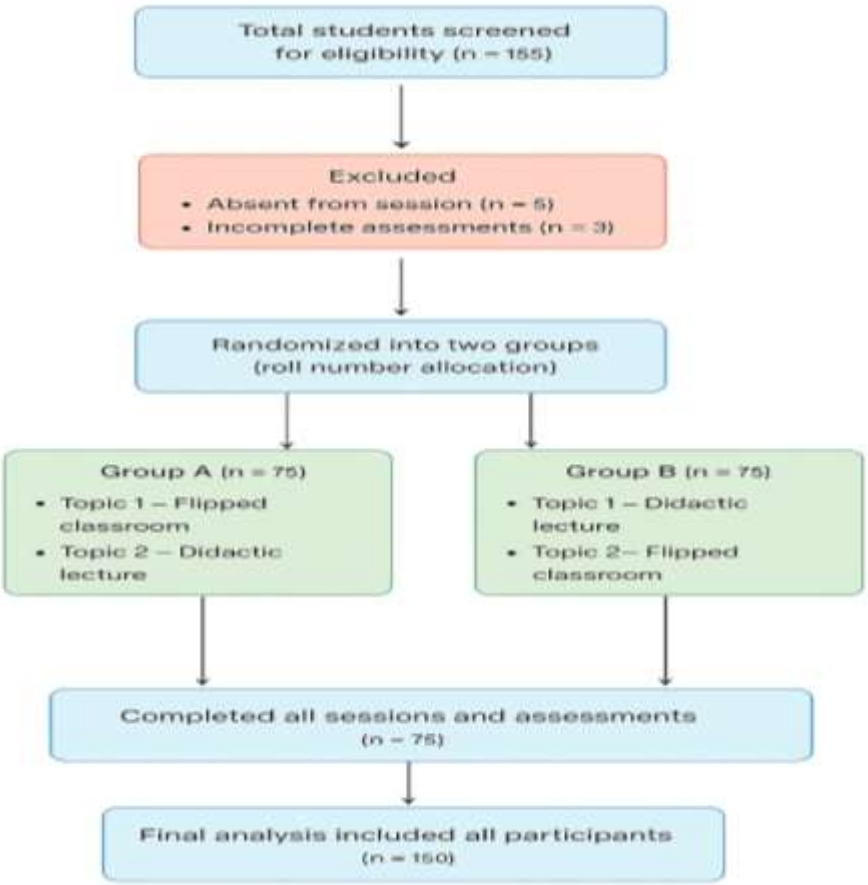

Figure :1. Participant Flow Diagram

The socio-demographic profile of the 150 participating first-year MBBS students is summarized in Table 1. The mean age was 19.4 ± 0.8 years, with a nearly equal gender distribution (48% male and 52% female). A majority resided in hostels (74.7%) and had no prior exposure to flipped
learning approaches.

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Table 1. Baseline Socio-Demographic Characteristics of the Participants (n = 150)

Parameter	Category	Number of Students (n)	Percentage (%)
Age (years)	18–19	92	61.3
	20–21	50	33.3
	≥22	8	5.4
Mean ± SD	—	19.4 ± 0.8	—
Gender	Male	72	48.0
	Female	78	52.0
Educational Background	State Board	89	59.3
	CBSE/ICSE	61	40.7
Residence Type	Hostel	112	74.7
	Day Scholar	38	25.3
Previous Exposure to Flipped Learning	Yes	26	17.3
	No	124	82.7

Table A1: Topic 1- Histology of Stomach, Number of students who attended and responded to the questionnaire

Group	Total Students Allotted	P1 (Pre-test)	P2 (Mid-test)	P3 (Post-test)
Group A – Flipped Classroom (1–75)	75	41	71	60
Group B – Didactic Lecture (76–150)	75	67	NA	66

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test; NA – Not Applicable (mid-test not conducted for Group B).

Table A2: Topic 1- Histology of Stomach

Group	Total Students Allotted	P1 + P2 + P3	P2 + P3	P1 + P3
Group A – Flipped Classroom (1–75)	75	30	58	30
Group B – Didactic Lecture (76–150)	75	NA	NA	66

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test; NA – Not Applicable (corresponding tests not conducted for Group B).

Table A3: Topic 1- Histology of Stomach

Group	Test	Mean	Median	Mode	Standard Deviation
Group A – Flipped Classroom (1–75)	Pre-test (P1)	8.03	9	10	2.33
	Mid-test (P2)	7.38	7	9	2.29
	Post-test (P3)	8.72	9	9	1.85
Group B – Didactic Lecture (76–150)	Pre-test (P1)	6.81	7	6	2.01
	Post-test (P3)	9.95	10	11	1.30

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test.

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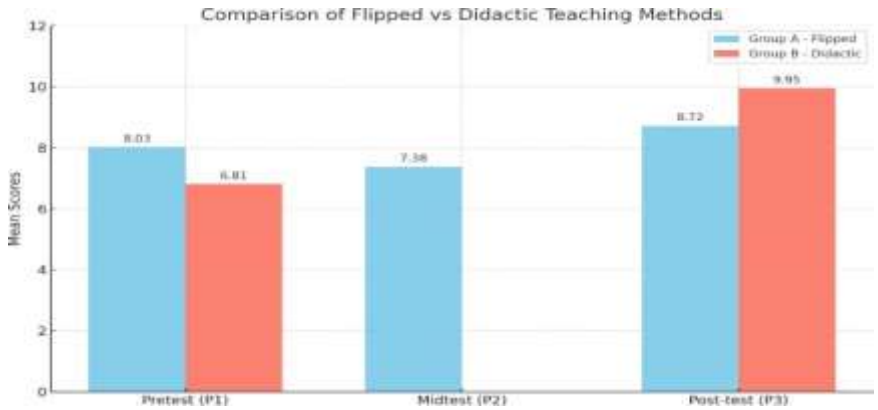
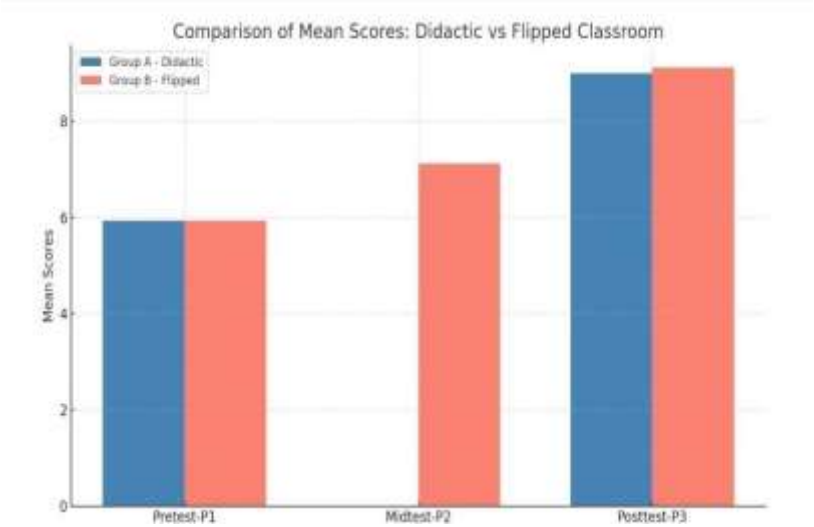


Graph A: Topic 1, Group A (Flipped Classroom) and Group B (Didactic Lecture) across the test phases.



Graph B: Topic 2, Group A (Didactic Lecture) and Group B (Flipped Classroom) across the test phases.

Table B1: Topic 2- Histology of Small Intestine, Number of students who attended and responded to the questionnaire

Group	Total Students Allotted	P1 (Pre-test)	P2 (Mid-test)	P3 (Post-test)
Group A – Didactic Lecture (1–75)	75	30	NA	30
Group B – Flipped Classroom (76–150)	75	42	42	42

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test; NA – Not Applicable (mid-test not conducted for Group A).

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Table B2: Topic 2- Histology of Small Intestine

Group	Total Students Allotted	P1 + P2 + P3	P2 + P3	P1 + P3
Group A – Didactic Lecture (1–75)	75	NA	NA	30
Group B – Flipped Classroom (76–150)	75	42	42	42

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test; NA – Not Applicable (corresponding assessments not conducted for Group A).

Table B3: Topic 2- Histology of Small Intestine

Group	Test	Mean	Median	Mode	Standard Deviation
Group A – Didactic Lecture (1–75)	Pre-test (P1)	5.93	5	5	1.62
	Post-test (P3)	9.00	9	10	1.19
Group B – Flipped Classroom (76–150)	Pre-test (P1)	5.93	6	4	2.40
	Mid-test (P2)	7.12	7	5	2.05
	Post-test (P3)	9.12	10	10	1.65

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test.

Table C1: Flipped v/s didactic lecture for topic 1, topic 2, with pretest, midtest, and posttest scores

Group	Test	Mean	Median	Mode
Didactic Lecture	Pre-test (P1)	6.37	6.0	5.5
	Post-test (P3)	9.48	9.5	10.5
Flipped Classroom	Pre-test (P1)	6.98	7.5	7.0
	Mid-test (P2)	7.25	7.0	7.0
	Post-test (P3)	8.92	9.5	9.5

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test.

Table C2: Flipped classroom V/s Didactic lecture

Group	Test	Mean	Median	Mode	Standard Deviation
Didactic Lecture	Pre-test (P1)	6.37	6.0	5.5	1.94
	Post-test (P3)	9.48	9.5	10.5	1.33
Flipped Classroom	Mid-test (P2)	7.25	7.0	7.0	2.17
	Post-test (P3)	8.92	9.5	9.5	1.73

Footnote: P1 – Pre-test; P2 – Mid-test; P3 – Post-test.

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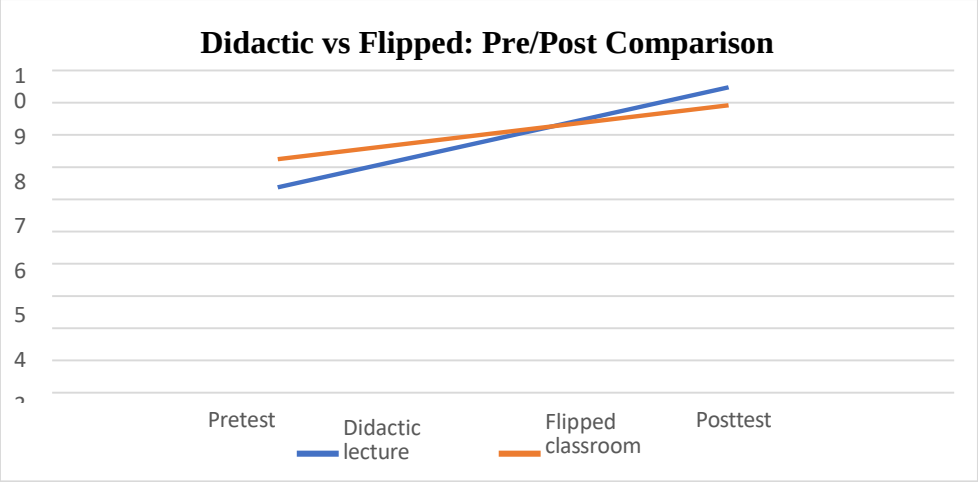

Graph C2: Showing the comparison of pretest and posttest scores among didactic lecture and flipped classroom teaching. (* in flipped classroom mid mid-test scores considered as pretest scores)

Table D: Flipped classroom V/s Didactic lecture, with p-value

Group	No. of Students (n)	Pre-test Mean*	Post-test Mean	*p*-value (within group)
Didactic Lecture	96	6.37	9.48	< 0.00001
Flipped Classroom	100	7.25	8.92	0.00000003

Between-Group Comparison	Pre-test *p*-value	Post-test *p*-value
Didactic vs. Flipped	0.0031	0.117

Footnotes:

- *In the flipped classroom, mid-test scores were considered as pre-test scores.*
- *Statistical tests used: Paired t-test for within-group comparisons (dependent observations); Independent samples t-test/Welch's test for between-group comparisons (independent observations).*
- *Software used: SPSS*

Discussion

The present analysis indicates that for Topic 1, didactic lectures were more effective in achieving short-term learning gains. As shown in Table A3, participants in the didactic group demonstrated a greater increase in mean scores from pre-test to post-test compared to those in the flipped classroom group. This improvement may be attributed to the structured, teacher-led delivery, which likely addressed knowledge gaps more effectively. In contrast, although the flipped classroom group began with a higher baseline score, the relative gain was limited. This may reflect challenges associated with self-directed learning, including variability in learner engagement, readiness for autonomous learning, and the degree of alignment between pre-class preparation and in-class activities.

In Topic 2, both groups began with an identical pre-test mean score (5.93), establishing a comparable baseline for evaluating instructional effectiveness. The didactic lecture group exhibited a substantial improvement in post-test scores (mean = 9), as shown in Table B3, suggesting that traditional teacher-centered instruction effectively

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facilitated knowledge acquisition. While the flipped classroom group achieved similar final scores, the progression was more gradual. The modest improvement observed in this group may reflect variability in how learners engaged with preparatory materials or inconsistencies in the implementation of the flipped methodology.

Overall, comparison of both modalities (Table C1 and Graph C) shows that the didactic lecture produced a notable jump from pre-test (P1) to post-test (P3), whereas the flipped classroom demonstrated a steady and gradual progression from pre-test through mid-test (P2) to post-test. Both teaching methods significantly improved learning outcomes; however, the didactic lecture showed greater short-term efficacy, likely due to its structured format, consistent pacing, and direct instructional guidance. The flipped classroom, while fostering learner autonomy and deeper engagement, may require enhanced scaffolding and stronger preparatory alignment to achieve equivalent academic outcomes.

Data from Table C further support these findings. Both instructional methods yielded measurable performance gains; however, the didactic group demonstrated a sharper improvement, whereas the flipped classroom group showed a gradual and sustained trajectory, suggesting different cognitive processing or retention mechanisms.

These findings partially align with previous studies reporting superior outcomes with flipped classroom instruction [6,11,12]. However, other studies have demonstrated comparable post-test performance between the two teaching methods, particularly when initial pre-test scores were higher in the flipped classroom group [13]. These observations underscore that the success of an instructional approach depends on contextual factors such as learner readiness, engagement, and instructional design rather than the method alone.

Conclusion

This study highlights the comparative effectiveness of the flipped classroom and traditional didactic lecture methods in teaching anatomy to undergraduate medical students. While both approaches demonstrated improvements in student performance, didactic lectures showed a greater short-term gain in test scores, particularly in contexts where structured delivery facilitated the closure of knowledge gaps. The flipped classroom model, however, promoted learner autonomy, peer interaction, and engagement, suggesting its potential for fostering deeper, long-term understanding when implemented with adequate scaffolding and student preparation.

These findings underscore the need for a balanced and context-sensitive approach to instructional design in medical education. Flipped classroom strategies may not uniformly outperform traditional lectures, but when carefully planned and aligned with learner readiness, they can significantly enrich the educational experience. Future studies should explore longitudinal outcomes, retention beyond the immediate post-test phase, and the integration of blended models to optimize learning in anatomy and other foundational subjects.

Limitations and Generalizability

This study has certain limitations. First, it was conducted in a single institution with a relatively small cohort of first-year MBBS students, which may limit the external validity of the findings. Second, only two histology topics were included, and results may differ if a broader range of subjects or disciplines were assessed. Third, the evaluation of knowledge retention was limited to short-term outcomes, and long-term retention or impact on clinical application was not measured. Additionally, response bias could not be entirely ruled out, as students were aware of being studied.

Despite these limitations, the crossover design, use of validated assessment tools, and inclusion of the entire class cohort enhance the reliability of the findings. However, generalizability is restricted, and results should be interpreted with caution when extrapolating to other medical colleges, subjects, or levels of medical training. Future multi-center studies with larger and more diverse student populations, inclusion of multiple subjects, and long-term follow-up are recommended to strengthen the evidence base.

Recommendations

Based on the findings of this study, it is recommended that the flipped classroom approach be increasingly incorporated into medical education as a complementary strategy to traditional didactic lectures. Flipped classroom teaching fosters active learning, student engagement, and better short-term knowledge retention, and may therefore be particularly useful for concept-driven subjects such as anatomy and histology. However, successful implementation requires adequate preparation time, structured study materials, and strong faculty facilitation to guide discussions. Institutions should consider integrating flipped classroom sessions periodically into the curriculum rather than relying exclusively on either method, thereby offering a blended approach that combines the advantages of both strategies. Further multi-center studies involving

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diverse medical student populations and long-term follow-up are recommended to validate and expand upon these findings.

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List of Abbreviations

- **MBBS** – Bachelor of Medicine, Bachelor of Surgery
- **MCQ** – Multiple Choice Question
- **P1** – Pre-test
- **P2** – Mid-test
- **P3** – Post-test
- **SD** – Standard Deviation
- **SPSS** – Statistical Package for the Social Sciences
- **IEC** – Institutional Ethics Committee

Source of Funding

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to this study.

Authors' Contributions

Kavya contributed to the conceptualization, study design, data collection, data analysis, and manuscript drafting. **G. S. P.** provided a critical review of the methodology, supervision, and intellectual input in manuscript preparation. **B. R. R.** guided the study design, validated the results, and provided overall supervision of the project. **S. K. L**. assisted with data collection, organization, and literature review. **Y. A. B.** was responsible for statistical analysis, interpretation of results, and manuscript editing. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

Data Availability

All datasets analyzed during this study are included in the manuscript.

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