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Knowledge acquisition and student perceptions of three teaching methods: a randomized trial of live, flipped, and interactive flipped classrooms

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Abstract

Background Traditional lecture-based learning has been the cornerstone of dental education; however, active learning strategies such as flipped classrooms are gaining popularity for their potential to enhance student engagement and performance. This study evaluated the effectiveness of three teaching methods—traditional live lectures, flipped video classrooms, and interactive flipped classrooms—on improving academic performance and student perceptions among fourth-year dental students.

Methods This study employed a stratified randomization design involving 156 fourth-year dental students using a single lecture in an undergraduate orthodontics course. The students were first grouped into four categories based on their Grade Point Average (GPA): Excellent, Very Good, Good, and Satisfactory. From these groups, students were randomly drawn and placed into one of three intervention groups: live lecture, flipped classroom with video lectures, and flipped classroom with interactive video lectures. Pre- and post-intervention assessments evaluated knowledge improvement, while objective structured assessments measured academic performance. Student perceptions were gauged using validated Likert-scale questionnaires. Paired t-tests assessed within-group differences, and ANOVA compared effectiveness across teaching methods. Pearson's correlation analysis examined the relationship between academic performance and GPA of the students.

Results All three teaching methods showed significant improvements in post-intervention scores ($p < 0.001$). The Live Lecture Group had the greatest mean improvement (27.69), followed by the Flipped Video Lecture Group (27.30) and the Flipped Interactive Lecture Group (27.11). However, ANOVA revealed no statistically significant differences between the groups (F (2, 153) = 0.007, $p = 0.993$). Female students performed better in the live lecture setting (32.60 ± 25.08) compared to males (23.79 ± 21.44). Students with lower GPAs benefited most from the interactive flipped classroom, Pearson's correlation indicated a strong positive association between GPA and post-intervention scores ($r = 0.708$, $p < 0.001$). Student satisfaction was highest in the interactive flipped classroom, with 97.7% rating the experience as "Excellent" or "Very Good."

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Conclusions All three teaching methods led to significant improvement in post-test scores. While students reported higher engagement and satisfaction in flipped and interactive flipped lectures, the live lecture method was also effective for knowledge retention. These findings highlight the importance of tailoring educational strategies to diverse student needs in dental education. Educators should consider a blended model that integrates flipped and traditional strategies selectively, balancing feasibility with student needs, as developing multiple formats can be time-intensive with only modest differences in outcomes.

Clinical trial number Not applicable.

Keywords Flipped classroom, Dental education, Teaching methods, Student performance, Student satisfaction

Background

With the evolving dynamics of student lifestyles and the rapid advancements in educational technology, academic institutions are increasingly embracing more adaptable learning environments that cater to the needs of contemporary learners. A particularly noteworthy innovation within this context is the flipped classroom model, a sophisticated form of blended learning that shifts the focus towards student-centered pedagogy by inverting conventional instructional methods. In this approach, students engage with new content independently outside the classroom—typically through video lectures or assigned readings—and subsequently participate in interactive, problem-solving exercises during in-class sessions [1].

In the domain of medical and dental education the flipped classroom model has garnered considerable attention due to its potential to offer diverse pedagogical benefits. Research has consistently demonstrated its capacity to enhance student engagement, foster active learning, cultivate critical thinking, and facilitate long-term retention of knowledge [2–4]. Compared to traditional lectures, flipped classrooms have been associated with significant improvements in immediate assessment scores, positioning them as an effective strategy for boosting student performance [5, 6]. Notably, a comprehensive meta-analysis by Bredow et al. (2021) revealed that flipped learning frameworks in higher education markedly improved both student performance and engagement relative to traditional pedagogical methods, thus reinforcing the relevance of this approach in contemporary educational practice [7].

A key element of the flipped classroom is the video lesson or video-recorded lecture, which delivers educational content in a multimodal format that may include instructor-led videos, visuals, textual information, or an integrative blend of these mediums. This versatility enables students to interact with the material according to their individual learning preferences, thereby promoting deeper engagement during subsequent in-class activities [8]. The strategic incorporation of interactive elements—such as embedded quizzes, matching tasks, and applied exercises—further augments the learning process by sustaining student attention and fostering a simulated interaction between the learner and the content [9].

While flipped learning has shown promising outcomes, research comparing live lectures, flipped classrooms, and interactive flipped classrooms remains limited. Some studies suggest that flipped learning enhances student engagement and performance [3, 6], whereas others indicate that traditional lectures still hold significant value, particularly for topics requiring direct instructor guidance and real-time feedback [10]. Additionally, interactive learning strategies, such as team-based and problem-based learning, have been found to improve critical thinking skills and retention in health education [11, 12].

One of the foremost strengths of the flipped classroom model lies in its ability to provide students with enhanced opportunities for collaborative and self-directed learning, coupled with the flexibility to manage their study time outside the formal classroom environment [13]. Students generally perceive this approach as effective, citing improvements in engagement and academic performance [14]. However, while the benefits of the flipped classroom are well documented, there remains a gap in the literature regarding the comparative effectiveness of different flipped learning variations, including the integration of interactive components, particularly in dental education [15].

This study aims to address this gap by evaluating both students' learning outcomes and their perceptions of three different teaching methods in dental education: live lectures, video-recorded sessions, and interactive flipped lectures. The influence of these methods on the academic performance and perceptual responses of fourth-year dental students will be thoroughly assessed, offering insights into the pedagogical efficacy and potential limitations of embedding interactive elements into the flipped classroom framework.

Study objectives

This study aims to evaluate the effectiveness of three different teaching methodologies—live lectures, flipped classrooms, and interactive flipped classrooms—in dental education. Specifically, it examines their impact on

student academic performance and satisfaction, providing insights into how interactive elements influence learning outcomes.

Materials and methods

Trial design

This study employed a parallel group, multi-arm, randomized experiment with an allocation ratio of 1:1:1. among three teaching methods: live lecture, flipped video lecture, and interactive flipped lecture. The study design remained unchanged after commencement.

Ethical approval

Ethical approval was granted by the Research Ethics Committee at the Deanship of Graduate Studies and Research (Approval No: D-F-H-18-Oct), and all participants provided informed consent.

Participants and eligibility criteria

Eligible participants were fourth-year dental students enrolled in "Clinical Orthodontics I." Students from other academic years or those who had previously withdrawn from the course were excluded.

All participants in the study provided their consent before starting.

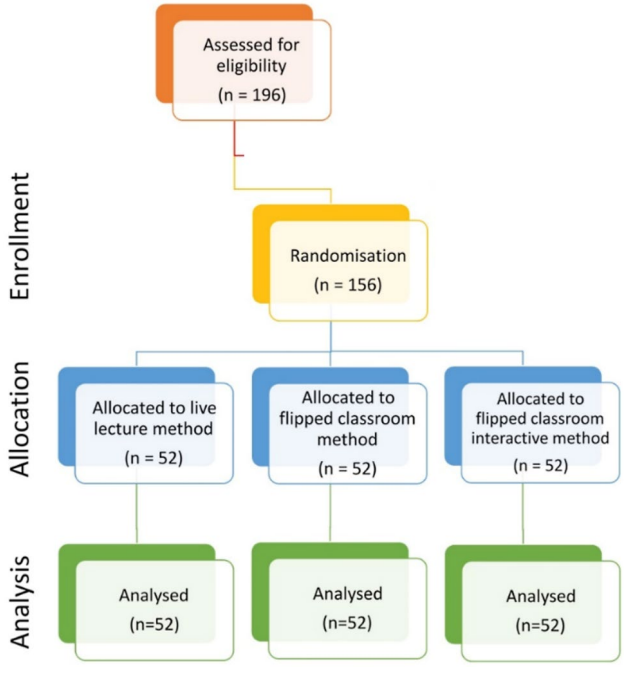


Fig. 1 CONSORT diagram showing the flow of participants throughout the study. The diagram illustrates the process of randomization, allocation to the three intervention groups (Live Lecture, Flipped Video Lecture, and Flipped Interactive Lecture), and participant flow during pre- and post-test assessments.

Randomization

Students were categorized based on their GPA into four categories (following the university GPA grading system): Excellent (GPA 3.6-4), Very Good (GPA 3.0-3.59), Good (2.5–2.99), and Satisfactory (2.0-2.49). Each student's name, along with their GPA classification, was written on a paper slip, folded, and placed into one of four corresponding GPA-specific boxes labeled 'Excellent,' 'Very Good,' 'Good,' and 'Satisfactory.'

Once all names were assigned, the papers were unfolded and listed under their respective study models. This stratified randomization resulted in balanced groups of 52 students in each intervention. A total of 156 students participated in the study. The study design and the flow of participants throughout the research process are illustrated in Fig. 1.

Intervention

This study was conducted during the second half of the semester to avoid conflicts with midterm and final exams. The topic 'Treatment Planning in Orthodontics I' was selected because it combines both fundamental educational concepts and higher-level critical thinking skills within the curriculum. The lecturer (AS) used the Clinical Orthodontic I Theory course syllabus to produce the lecture presentation, which serves as the sole source of material for the three instructional techniques: live lectures, flipped video recorded lectures, and flipped interactive lectures. The instructor (AS) filmed the presentation on screen while also recording the audio for the lecture's content. The speaker followed the presentation as a guide to ensure that the information was presented consistently, just as he would if it were a live lecture. The video was edited via Ulead VideoStudio 2018 (video editing software developed by Ulead System Company; https://www.videostudiopro.com/en/), and an interactive video for the flipped interactive lecture group was created via Mindstamp (video interactive platform developed by Mindstamp Company; https://mindstamp.io/). The recorded lectures did not include Closed Captioning; students engaged with the material through audio-visual content only.

The Flipped Video Lecture model allowed students to watch a pre-recorded lecture at their own pace, with the ability to pause, rewind, and review the content as needed. This intervention has no embedded activities. Conversely, the Interactive Flipped Lecture included engagement elements, such as in-video quizzes and interactive prompts, spaced every 7–10 min to enhance student engagement.

Assignment and assessment process

Students were randomly assigned to one of the three intervention groups and received detailed instructions on

their designated lecture format and attendance requirements. A formal announcement was made a day before the study, informing students of their group allocation and session details.

The Live Lecture group attended a 35-minute in-person lecture in Hall 1 of the College of Dentistry, whereas students in the Flipped Video Lecture and Interactive Flipped Lecture groups were required to watch their assigned lecture within two days before attending the mandatory in-person discussion session. Students accessed them via the university's online portal, where completion was monitored to ensure compliance.

After completing their respective lectures, all students attended a mandatory single, standardized Q&A session in Hall 1, moderated by the same instructor to maintain consistency across groups. To ensure assessment integrity, students were explicitly instructed not to consult external resources while taking the quizzes. The post-intervention quiz was locked and administered in a supervised, in-person setting at the university, immediately following the Q&A session. This prevented students from collaborating or sharing answers between groups.

After completing the 10-item multiple-choice post-quiz, students were provided with their designated questionnaire, adapted from validated instruments, to assess their perceptions of their assigned teaching method. The surveys were distributed via Microsoft Forms to facilitate data collection.

Importantly, quiz scores were collected solely for research purposes and were not included in students' official course grades.

Live lecture group Students in this group attended a 35-minute live lecture delivered in Hall 1 of the College of Dentistry. The session allowed for direct interaction with the instructor, enabling real-time questioning and clarification of concepts.

Before the lecture, students completed a 10-item multiple-choice pre-intervention test. Following the lecture, students participated in the standardized Q&A session, after which they completed the post-intervention quiz and perception questionnaire (Supplementary File 1).

Flipped video recorded lecture group Students in this group were given access to a 35-minute video-recorded lecture, which they could watch on their devices at home at their preferred pace. The lecture did not contain embedded interactive elements.

- Pre-intervention test: Completed before watching the video.
- Post-intervention test: Administered after the in-person Q&A session in a supervised environment, ensuring no access to external resources.
- Questionnaire: Distributed after the post-test to assess student perceptions (Supplementary File 2).

Flipped interactive lecture group

Students in this group received a 35-minute interactive video, created using Mindstamp, which included embedded quizzes, interactive questions, and prompts every 7–10 min to enhance engagement.

- Pre-test: Completed before starting the video.
- Post-test: Taken in-person immediately after the Q&A session, under the same conditions as other groups.
- Questionnaire: Administered after the post-test to evaluate student perceptions (Supplementary File).

Blinding

The quiz questions were developed by one of the authors (HA), who was blinded to the specifics of each teaching method. HA used only the lecture's learning objectives to design the questions, ensuring that the lecturer (AS) had no prior knowledge of the quiz content to avoid giving students any hints throughout the presentation. The teaching method could not be concealed from the students.

Outcome measures

Academic Performance: Knowledge acquisition was measured using pre- and post-test scores on multiple-choice quizzes specifically designed for each intervention group to objectively assess academic performance improvements. Ten questions in the form of MCQs on Microsoft forms were given to the students before and after the intervention by one of the researchers (HA), who used the presentation as a reference.

Student Perceptions: The survey questionnaire assessing student perceptions of each teaching method was adapted from a validated instrument used by Shqaidef et al. (2020) [10] in a similar dental education context. Minor modifications were made (e.g., removal of some questions) to fit the study's scope. The instrument was pilot-tested with a small group ($n = 12$) to confirm suitability. Responses were collected on a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree and strongly disagree) and analyzed to gauge student engagement and satisfaction. The students were asked to answer the questionnaire via a link (depending on which study group they belonged to) using Microsoft forms for easy analysis and information gathering. The final questionnaires for each group are provided in Supplementary Files 1–3.

Grade Point Average (GPA), a cumulative measure of a student's academic performance, was calculated on a scale from 0 to 4. GPA scores. The GPA scores were

based on the average of students' grades from the last three years of study and were used as an indicator of overall academic achievement and were factored into the analysis to evaluate the correlation between prior academic performance and the effectiveness of each teaching method.

Sample size calculation

A power analysis was conducted using a one-way ANOVA F-test to determine the appropriate sample size for this study. The analysis was based on an expected effect size (Cohen's d) of 0.4, which is considered a moderate effect size in educational research. The standard deviation of the variation in the means was set at 0.82, while the common standard deviation within a group was assumed to be 1.00 [16, 17]. The desired statistical power was set at 0.95 with a significance level (alpha) of 0.05, which is standard for detecting meaningful differences between groups. Based on these parameters, the power analysis indicated that a minimum of 96 participants (32 per group) would be required to detect a statistically significant difference between the teaching methods.

However, to improve statistical power, account for potential attrition, and ensure adequate representation across all GPA categories—including the relatively smaller "Satisfactory" group—we invited all 196 students enrolled in the course to participate, but attendance was voluntary as participation could not be mandated for ethical reasons. A total of 156 students attended voluntarily and were randomized into three intervention groups (52 students per group). This adjustment enhanced the study's robustness by capturing performance variations across the full academic spectrum. This increase in sample size did not negatively impact statistical validity; instead, it improved the reliability of the findings by reducing the risk of underpowering the analysis.

Due to ethical considerations and academic policy, a true control group was not included in the current study, as withholding instruction on core curriculum material would not be permitted.

Table 1 Demographic characteristics of the participants

Variable	Group	*N*	Percentage
Gender	Male	54	34.6%
	Female	102	65.4%
Intervention Group	Live Lecture	52	33.3%
	Flipped classroom	52	33.3%
	Interactive flipped classroom	52	33.3%
Continuous Variables			
Variable	**Mean ± S. D**	**Minimum**	**Maximum**
Age	21.16 ± 1.28	19	29
GPA	3.30 ± 0.46	2.00	3.73

Table 1: This table summarizes the distribution of participants by gender and intervention group. It also presents continuous variables including age and GPA, with respective means, standard deviations (SD), minimum, and maximum values

Data collection and statistical analysis

Data on students' pre- and post-intervention quiz scores were collected through Microsoft Forms for automated scoring. Perceptions of each teaching method were also gathered via the questionnaire distributed through Microsoft Forms.

Statistical analyses included paired t-tests to assess within-group pre- and post-intervention differences and one-way ANOVA to compare scores across the three groups. Pearson correlation analysis evaluated the association between GPA and post-test performance. *p*-values were set at 0.05 for significance.

Results

Participant demographics

In the study population, there was a notable difference in sex distribution; 34.6% were males ($n = 54$), and 65.4% were females ($n = 102$). When the intervention groups were examined, the distribution was evenly balanced. Each of the three intervention methods—live lecture, flipped video lecture, and flipped interactive lecture—had an equal share of participants, with each method accounting for 33.3% ($n = 52$) of the total participants. The average age of the participants in the study was 21.16 ± 1.28 years, ranging from the youngest at 19 years to the oldest at 29 years. In terms of academic performance, the participants had a mean GPA of 3.30 ± 0.46, with the lowest being 2.00 and the highest reaching 3.73 (Table 1).

Intervention outcomes

Pre- and post-intervention scores

The three teaching methods showed significant improvements in post-intervention scores across all groups, as detailed in Table 2. In the Flipped Video Lecture Group, the mean difference between pre- and post-intervention scores was 27.30, with a 95% confidence interval ranging from 20.15 to 34.45 (t (51) = 7.66, $p < 0.001$.). The Interactive Flipped Lecture Group showed a mean difference of 27.11, with a confidence interval of 19.77 to 34.45 (t (51) = 7.41, $p < 0.001$). The Live Lecture Group had a mean difference of 27.69, with a 95% confidence interval between 21.20 and 34.18 (t (51) = 8.56, $p < 0.001$). For further details on these comparisons, please refer to Table 2.

In assessing the variability in scores between and within the groups, a one-way ANOVA test was employed to determine whether there were significant differences in the effectiveness of the three teaching methods. The analysis showed no significant difference between the groups, with an F (2, 153) = 0.007, $p = 0.993$. The assumptions of ANOVA were tested using the Shapiro-Wilk test

Table 2 Pre- and Post-Intervention scores across three teaching methods

Variable	Group	N	Mean ± S. D	Mean Difference	95% Confidence Interval of the Difference		t	df	Sig.
					Lower	Upper			
Flipped Classroom Group	Pre	52	52.11 ± 19.23	27.30	34.45	20.15	7.66	51	$p < 0.001$
	Post	52	79.42 ± 19.03						
Interactive Flipped Classroom	Pre	52	49.03 ± 17.74	27.11	34.45	19.77	7.41	51	$p < 0.001$
	Post	52	76.15 ± 19.81						
Live Lecture Group	Pre	52	53.65 ± 18.36	27.69	34.18	21.20	8.56	51	$p < 0.001$
	Post	52	81.34 ± 17.93						

Table 2: This table presents the mean pre- and post-intervention scores for the Live Lecture, Flipped Classroom, and Interactive Flipped Classroom groups. It also includes the mean difference between the pre- and post-scores, 95% confidence intervals (CI), and t-values, with significance levels ($p < 0.001$). SD = Standard deviation, t = t-value for t-test, df = degree of freedom, Sig. =level of Significance

for normality and Levene's test for homogeneity of variance, and both were satisfied.

Additionally, the effect size, calculated as eta squared, was found to be $\eta^2 = 0.009$. This low value suggests that the variability in post-intervention scores due to different teaching methods is minimal, indicating a negligible practical impact. As the results were not significant, post-hoc comparisons were not conducted, as they would not yield meaningful insights.

Differences in performance between male and female participants were observed across the three teaching methods. For the Flipped Classroom approach, male participants had a mean score of 26.92 ± 30.10, whereas female participants scored slightly higher at 27.43 ± 24.46. However, this difference was not statistically significant ($p = 0.956$). Similarly, in the interactive flipped classroom, males scored 27.22 ± 24.68, and females scored 27.94 ± 22.93, with no significant difference ($p = 0.919$). Interestingly, for the live lecture method, a more pronounced difference was noted, where male participants scored 23.79 ± 21.44, whereas females scored significantly higher at 32.60 ± 25.08, with this difference approaching statistical significance ($p = 0.048$). (See Supplementary File 4 Additional File, Table A1 illustrating the differences in performance between male and female participants in the three groups)

Correlation analysis

A Pearson correlation analysis was conducted to evaluate the relationships between students' GPAs and their improvement in test scores, measured as the difference between post-test and pre-test scores. The resulting correlation coefficient was found to be $r = 0.708$, indicating a strong positive association between GPA and knowledge gain across all teaching methods ($p < 0.001$). This suggests that students with higher GPAs demonstrated greater improvement following the intervention. The Correlation is significant at the 0.01 level (2-tailed).

Analysis of teaching methods

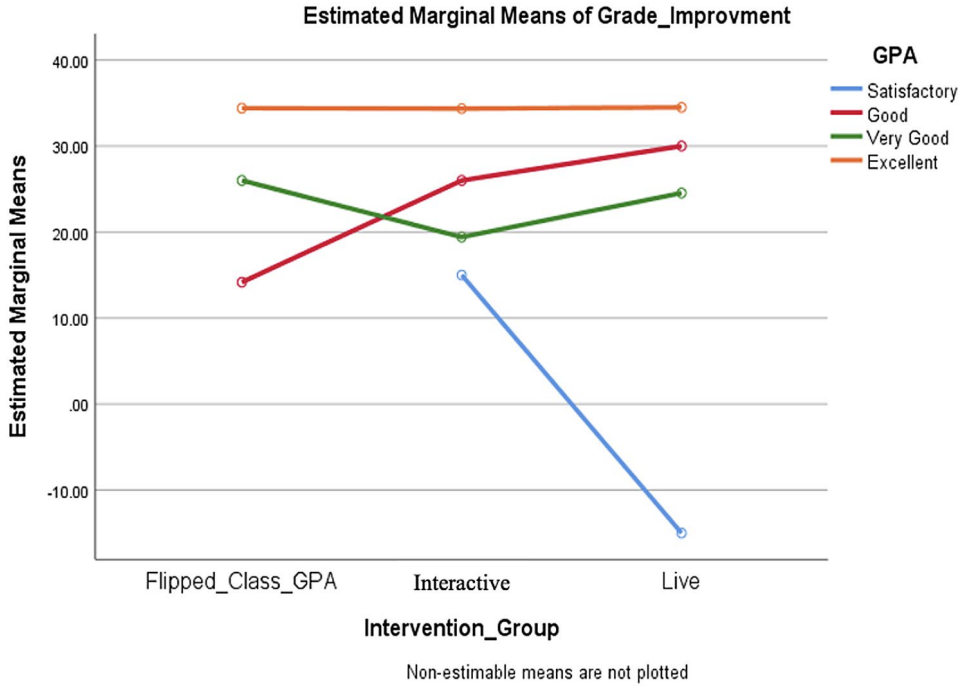
The analysis of teaching methods' impact on student performance across different GPA categories showed distinct patterns. Students with 'Excellent' GPAs displayed consistent performance across all methods, with minimal variation. For those in the 'Good' category, scores improved from 12 with the flipped video lecture to 28 with the flipped interactive method, but the highest gains were observed with the live lecture. 'Very Good' GPA students benefited most from the live lecture method, with a decline noted when switching from the flipped video to the flipped interactive method. In contrast, 'Satisfactory' students showed greater variability, with scores dropping significantly when shifting from the flipped interactive to the live lecture method. Detailed trends are depicted in Graph 1.

Participant feedback

Students provided feedback on their learning experiences of the three teaching methods used in the study, offering valuable qualitative and quantitative insights into engagement and satisfaction levels. At the end of each survey, students rated their overall learning experience as either "Excellent", "Very Good", "Same", "Poor", and "Very Poor". *(The survey questions used to assess student perceptions of each teaching method are provided in detail in Supplementary Files*1–3.)

Flipped interactive classroom

The flipped interactive classroom received overwhelmingly positive feedback. A total of **97.7%** of students rated their learning experience as either "Excellent" (56.5%) or "Very Good" (41.2%). Students particularly valued the interactive features embedded within the video, such as quizzes and drawing exercises, which enhanced their concentration and understanding. **87.5%** of participants reported that being able to pause, replay, and interact with the content was highly beneficial, helping them engage more deeply with the material. These interactive elements were seen as crucial in promoting active learning and retention, as noted by **92.3%** of respondents who



Graph. 1 Estimated marginal means of grade improvement by teaching method. Visual representation of the performance of different GPA groups under each teaching method, highlighting the score changes and variations

felt this method facilitated a more personalized learning experience.

Live lecture group

Students in the live lecture group appreciated the traditional format, particularly the opportunity for real-time interaction with the instructor. **59.6%** of participants rated the method as "Very Good" and **40.4%** as "Good." Many students emphasized the value of immediate feedback from the instructor, with **83.6%** agreeing that real-time clarification of complex topics improved their understanding. Some students (20%) also highlighted the structured environment as beneficial for maintaining focus during the session. However, **15.6%** of participants noted that they felt less engaged compared to their peers in the flipped interactive group.

Flipped video lecture group

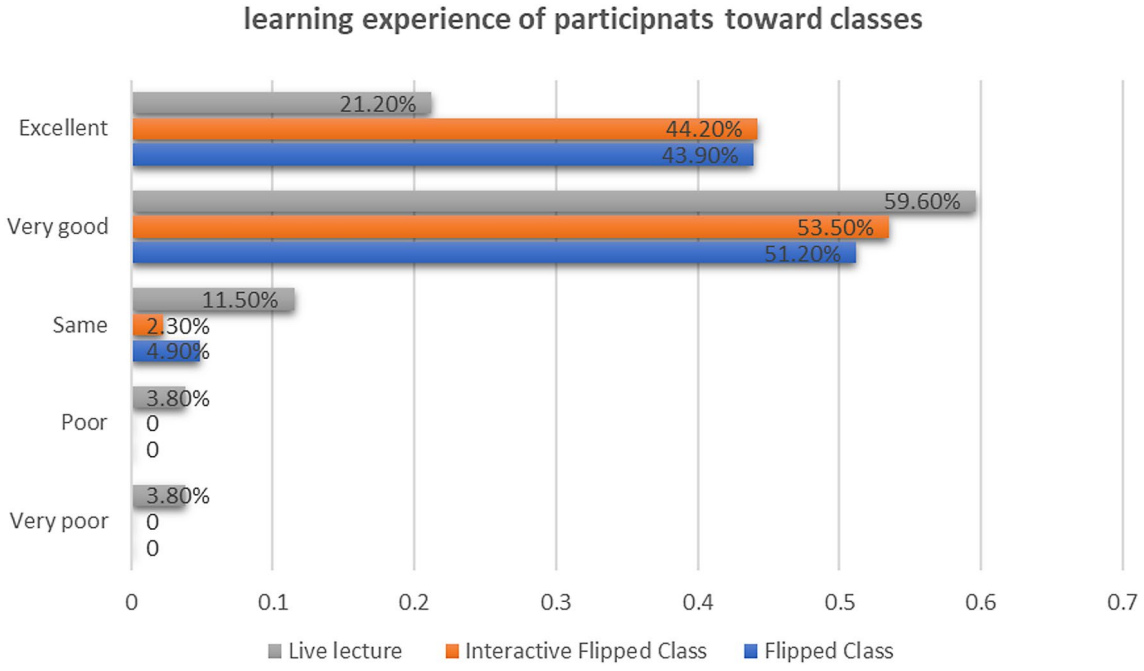
The flipped video lecture received generally favorable feedback, although less interactive than the flipped interactive model. **43.9%** of students rated their experience as "Excellent," and **51.2%** rated it as "Very Good." The flexibility of reviewing the lecture at their own pace was appreciated by **78.4%** of students, with **67.5%** indicating that this method allowed them to better understand the material compared to traditional live lectures. However, **31.2%** of respondents felt the absence of interactive elements made this method feel more passive, compared to the interactive flipped classroom model.

Overall, students demonstrated a preference for more interactive methods, with the flipped interactive lecture model receiving the highest satisfaction ratings. Nevertheless, each teaching method had distinct advantages, with students showing different preferences based on the level of engagement they sought. The Likert scale scores for all three groups are presented in Supplementary File 4(Tables A2, A3, A4). Graph 2 provides a comparative overview of student satisfaction across the three teaching methods.

Discussion

This study aimed to evaluate the effectiveness of three different teaching methods—live lecture, flipped classroom, and interactive flipped classroom—on the academic performance and satisfaction of fourth-year dental students. The results offer significant insights into the effectiveness of these pedagogical approaches, contributing to the broader body of literature on innovative teaching strategies in dental education.

The study demonstrated statistically significant improvements in student performance across all three teaching methods from pre-intervention to post-intervention, with the live lecture group showing the greatest improvement (mean difference of 27.69), followed closely by the flipped classroom (27.30) and interactive flipped classroom (27.11). These findings contrast with prior research, such as Chutinan et al. (2018), which reported superior learning outcomes in flipped classroom settings.



Graph. 2 Student satisfaction across teaching methods. This graph compares student satisfaction across the three teaching methods (Live Lecture, Flipped Classroom, and Interactive Flipped Classroom) based on Likert scale responses

A possible explanation for this discrepancy is that the impact of flipped learning may depend on factors such as content complexity, student adaptability, and how the flipped methodology is implemented [5]. Our study focused on a single lecture in a dental curriculum, whereas other studies have examined broader implementations across multiple sessions, potentially allowing for greater familiarity with the flipped model. The effectiveness of flipped learning may also be influenced by the extent of student engagement, prior knowledge levels, and the availability of interactive reinforcement during learning sessions.

Although this study primarily examines differences in content delivery, each teaching method included an interactive component. The flipped and interactive flipped classrooms, in particular, emphasized student engagement beyond passive content consumption, fostering deeper learning through structured interactions.

However, traditional live lectures still hold significant value, particularly for complex subjects that benefit from direct interaction with the instructor. This aligns with findings by Shqaidef et al. (2020), who noted that live lectures were more effective than recorded lectures in developing higher-order analytical thinking skills [10]. The results of the present study similarly suggest that while flipped and interactive methods are highly effective, traditional methods should not be disregarded, especially for topics requiring in-depth explanations and real-time feedback.

Student satisfaction was notably greater in the flipped and interactive flipped classroom groups than in the live lecture group, echoing the results of multiple studies that highlighted the higher reported satisfaction of student-centered, active learning environments. For example, Gianoni-Capenakas et al. (2019) conducted a systematic review and concluded that flipped learning improves student satisfaction due to its flexibility and ability to learn at one's own pace [13].

Interestingly, despite the higher satisfaction ratings, the performance in the interactive flipped classroom was not significantly superior to that in the standard flipped classroom. This suggests that while interactivity is valued by students, its impact on learning outcomes may be more nuanced. Previous research supports this finding; for example, Kohli et al. (2019) reported that while interactive and spaced learning methods enhance short-term performance, they do not significantly outperform traditional methods in long-term knowledge retention [18].

The Pearson correlation analysis in this study revealed a strong positive correlation ($r = 0.708$, $p < 0.001$) between student performance and GPA, indicating that students who perform well in general also excel under all three teaching methods. This correlation aligns with the findings of Qutieshat et al. (2020), who demonstrated that students with higher GPAs tend to perform better in both traditional and flipped learning environments [19].

It is worth noting that the subgroup of students with 'Satisfactory' GPA was relatively small, limiting statistical interpretation of their outcomes across all intervention

arms. Nonetheless, the observed trends suggest that this group benefited more from the flipped and interactive approaches. Future research with larger subgroup samples would allow for more definitive conclusions regarding the best teaching method for academically at-risk students.

While all three teaching methods were effective, the Flipped Video Lecture and Flipped Interactive Lecture methods were particularly beneficial for students with 'Good' and 'Very Good' GPA. Notably, students with 'Satisfactory' GPAs performed worse in the live lecture setting, which raises interesting questions about the effectiveness of traditional lectures for this group. One possible explanation is that these students may experience higher levels of stress and anxiety in a live lecture environment, which can negatively impact their performance. Previous research has suggested that low-achieving students often benefit more from lecture recordings than from live lectures, as they can review the material at their own pace and in a less stressful environment [20]. This finding aligns with the observation that traditional lecture settings might not fully support the needs of students who are already struggling academically.

In terms of gender differences, the study revealed that female students generally performed better in the live lecture setting than their male counterparts did. This finding is consistent with the literature, which suggests that female students tend to attend more lectures and achieve higher grades than male students do [21]. This may be due to differences in learning styles or preferences, with female students possibly benefiting more from the structured environment that live lectures provide. This finding warrants further investigation, as it may indicate that different teaching methods could be optimized on the basis of demographic factors to better serve diverse student populations.

The calculated effect size ($\eta^2 = 0.009$) in this study suggests a minimal impact of the teaching methods on post-intervention scores, which aligns with similar findings in medical [22] and dental [23] research, where effect sizes for educational interventions are often modest as numerous factors influence learning outcomes beyond the teaching method itself. This suggests that while each teaching method effectively enhanced student performance, differences in knowledge acquisition alone may not be substantial enough to favor one approach over another based solely on quantitative outcomes.

However, the high levels of student engagement and satisfaction—particularly in the flipped and interactive formats—highlight the perceived value of the learning experiencethese methods can offer. Integrating interactive elements into flipped classrooms can foster a more engaging and dynamic learning environment, which is crucial in fields like dental and medical education where active learning and critical thinking are emphasized. This underscores the importance of balancing quantitative outcomes with enhanced engagement provided by interactive methods.

This study adds to the growing body of literature advocating for interactive, student-centered teaching methods in dental education. The integration of flipped classrooms with interactive elements, such as quizzes and exercises, highlights the pedagogical shift toward active learning models. Our results align with studies such as Huang et al. (2020), which demonstrated the effectiveness of interactive learning in improving both knowledge acquisition and student satisfaction in medical education contexts [3]. Similarly, Wu et al. (2024) also highlighted that a flipped approach in dental implant education led to greater practical skill acquisition compared to conventional methods [6]. Our study contributes to this evolving pedagogical framework by underscoring the importance of personalizing educational strategies to meet diverse student needs who may not excel in traditional lecture-based environments.

Methodologically, this study illustrates the value of combining performance-based assessment (pre- and post-intervention tests) with perception-based feedback to provide a comprehensive view of teaching effectiveness. The stratified randomization by GPA added rigor, ensuring balanced groups reflective of academic diversity. For educators in both health and higher education fields, this research suggests that a blended model incorporating interactive and traditional lecture elements may be an adaptable and effective strategy. Such an approach can cater to a variety of learning preferences and enhance engagement, making it especially valuable in clinical and applied learning settings that demand hands-on skills and critical thinking.

The study's limitations should be acknowledged. First, the research focused on a single topic within the dental curriculum, which may limit the generalizability of the findings to other subjects or disciplines. The inclusion of pre- and post-class quizzes may have motivated the students to perform better, potentially skewing the results. Additionally, the study did not account for the long-term retention of knowledge, which is a critical aspect of evaluating educational outcomes.

Future research should aim to explore the long-term effects of these teaching methods on knowledge retention and practical application, particularly in clinical settings. Moreover, further studies could investigate the reasons behind the observed gender-based differences in performance, offering insights into how

educational strategies can be tailored to different learner groups.

Conclusion

This study highlights the importance of selecting appropriate teaching methods based on student performance levels and learning preferences. While flipped and interactive flipped classrooms offer significant advantages for many students, traditional lectures may still have a place, particularly for those who thrive in a structured, knowledge delivery and subjects requiring real-time instructor feedback. Educators should adopt blended approaches that integrate interactive and lecture-based elements to cater to diverse learning styles. Further research should explore long-term knowledge retention and the applicability of these methods across different disciplines in dental education.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-025-07156-0.

Supplementary Material 1: Live Lecture Questionnaire

Supplementary Material 2: Flipped Classroom Questionnaire

Supplementary Material 3: Interactive Flipped Classroom Questionnaire

Supplementary Material 4: Additional File 1 (containing the following tables)

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Author contributions
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Data availability
The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board (IRB) of Ajman University (protocol code D-F-H-18-Oct and date of approval: November 8, 2022). Informed consent was obtained from all participants involved in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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