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Effectiveness of error-based active learning compared to conventional lecture-based method among undergraduate dental students: A randomized controlled trial

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Abstract:

INTRODUCTION: Dental education assumes an indispensable role in adequately equipping students for a successful career in dentistry. Error-based active learning, an innovative approach in dental education, is a combination of mistake-driven learning (MDL) and case-based learning (CBL) to provide a transformative learning atmosphere for students. While active learning has gained popularity in dental education, the effectiveness of error-based active learning remains unexplored. This study aims to evaluate the effectiveness of error-based active learning among final-year dental undergraduate students in comparison with the conventional lecture-based approach.

MATERIALS AND METHODS: A parallel-arm single-blind randomized controlled trial was conducted in a dental institute in India from November 2022 to December 2022. A total of 74 students were randomly allocated to two groups: Group A (n = 37) received error-based active learning and group B (n = 37) received conventional lecture-based learning approach. Atraumatic restorative treatment (ART) was chosen as the topic for the study. The knowledge of students was assessed at three intervals: baseline, post-intervention, and 4 weeks after the intervention, using a self-designed and validated questionnaire with Cronbach's alpha of 0.87 and a content validity ratio of 0.84. A standard survey questionnaire was employed to evaluate students' perceptions of the teaching methods.

RESULTS: Error-based active learning group outperformed the lecture-based group significantly in the post-intervention test (20.92 ± 1.42 vs 16.97 ± 3.06), with better knowledge retention (18.30 ± 2.02 vs 14.05 ± 4.26) and positive feedback from the students.

CONCLUSIONS: The error-based active learning approach proved superior to the conventional lecture-based method in enhancing and retaining knowledge regarding ART.

Keywords:

Active learning, case-based learning, conventional lecture, dental education, mistake-driven learning

Introduction

Dental education plays a pivotal role in equipping students for a successful career in dentistry. To prepare them for the challenges ahead, it is crucial to offer a dynamic, engaging, and up-to-date education that keeps pace with the latest advancements in the field.[1] The conventional didactic lecture format, though efficient in imparting information to a large number of students, often results in passive

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learning that is teacher-centered. This form of learning does not encourage student interaction or the application of newly acquired knowledge.[2]

The concept of active learning has gained prominence in recent years, and it refers to "anything that involves students in doing things and thinking about the things they are doing."[3] These methods enhance student retention, recall, and cognitive processing.[4,5] Among the many active learning methods available, case-based learning (CBL) stands out as an established and interactive approach that promotes active learning through real-life case scenarios.[6,7] CBL has been combined with other teaching methods with great success and has been shown to increase knowledge, skills, overall abilities, and teaching satisfaction scores.[8–12]

To maximize learning outcomes, it is recommended that CBL employ cases that are practical, challenging, engaging, and instructional.[13] Mistake-driven learning (MDL), a less explored form of learning, offers great potential in the field of education by allowing students to learn from their mistakes and reflect on their experiences. MDL can be used as an adjunct to CBL to promote solution-oriented thinking, thereby, preparing students to handle problems in the workplace and improve clinic practices for better patient experience.[14]

However, there has not been any research on the use of MDL in dental education, either on its own or in combination with other methods. The objectives of this study were to assess the effectiveness of integrating CBL and MDL and compare it with the conventional lecture-based method as well as to evaluate student perceptions of these teaching approaches. The hypothesis is that this innovative approach can enhance knowledge acquisition and retention among dental students, leading to high-quality learning outcomes. These outcomes are essential for nurturing competency, improving patient care, and facilitating the professional development of future dentists. Conventional lecture-based formats may not fully achieve these outcomes, given their limitations in sustaining student engagement and attentiveness.[15,16]

Materials and Methods

Study design and setting

This was a parallel-arm single-blind randomized controlled trial conducted in a dental institute in Belagavi, India, between November 2022 and December 2022. The study was registered with the Clinical Trials Registry—India under the CTRI number CTRI/2022/11/047058 and followed the Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Study participants and sampling

The study was conducted among final-year dental undergraduate students. Students who provided informed consent and were present on the day of the baseline test were included. Conversely, those who declined to provide consent were not considered.

The sample size was calculated using the GPower program (G*Power version 3.1.9.4 statistical software) based on a similar study.[17] The resulting sample size was determined to be 56 students with a power of 0.90 and an alpha error of 0.05. To account for a potential dropout rate of 10%, the study ultimately included a total of 74 students evenly distributed with 37 students in each group.

Seventy-four students were randomized by simple random sampling technique into two groups using a computer-generated table of random numbers. Group A (n = 37) received error-based active learning technique, while group B (n = 37) received the conventional lecture-based technique. The sequentially numbered, opaque, sealed envelope (SNOSE) technique was used for allocation concealment. The randomization and allocation concealment procedures were conducted by an independent third party who was not directly involved in the study. Blinding was limited to the outcome assessor given the nature of this educational intervention.

Data collection tool and technique

Atraumatic restorative treatment (ART) is strongly endorsed by the World Health Organization and holds great significance, especially in outreach programs, as it offers a minimally invasive treatment approach for dental caries.[18] In this study, ART was the topic of choice for the students of final-year Bachelor of Dental Surgery (BDS), as also mandated by the Dental Council of India.[19]

Carefully curated teaching contents prepared and reviewed by experts were utilized in the teaching process. Both teaching approaches made use of audio–visual aids created with Microsoft PowerPoint (2020).

A self-designed questionnaire with 23 multiple-choice questions was developed to assess both theoretical knowledge and clinical application. Each question offered four options, with one correct answer, aligning with the cognitive levels of Bloom's Taxonomy: Remember, Understand, Apply, Analyze, Evaluate, and Create.[20] The "Remember" and "Understand" categories were merged to assess theoretical knowledge, while the remaining questions were considered indicators of clinical application.

The questionnaire was validated 3 months before the study by five subject experts. Comprehensibility, uniform difficulty, and completion time of 10 minutes

were confirmed. A pilot study with 10 final-year dental students assessed reliability (Cronbach's alpha = 0.87) and validity (content validity ratio = 0.84). These measures ensured the test's credibility and relevance for the study. This questionnaire was administered at baseline, post-intervention, and after 4 weeks.

A standard survey questionnaire with nine items on a Likert scale was used to assess the perception of the students on the teaching methods.[11] It covered overall satisfaction, engagement, skill development, and collaborative learning.

Ethical considerations

The study obtained ethical clearance from the Institutional Research and Ethics Committee, with reference number 1537, dated October 18, 2022. It was conducted in adherence to the ethical principles of human experimentation and in compliance with the Helsinki Declaration of 1975, as revised in 2000.

Phases of the study

Preparatory phase

Each student received a self-designed and reviewed reading material and a 5-minute video about ART 3 days before the intervention and was instructed to study on their own outside of class. The video featured a demonstration of the ART procedure conducted on a typodont model. It was sourced from YouTube https://youtu.be/8VOi4BDrEN8?si=q8bkI4dAmuS5-B60 and was subsequently tailored to suit the requirements of final-year students.

Baseline test

The questionnaire was distributed to all the students, and the responses were collected after a 10-minute duration under the supervision of the primary investigator and two assistants to assess authentic responses.

Intervention phase

Following the baseline test, students were randomly assigned to two groups, and the intervention was administered accordingly. The teaching session lasted for 60 minutes in both groups and was taught by the same investigator.

Error-based active learning technique

In this technique, four virtual clinical case scenarios were utilized, each containing multiple mistakes or misplaced clinical steps. The students in group A ($n = 37$) were divided into five smaller groups, four of which comprised eight students each, and one group with five students. The session commenced with a brief 10-minute overview of ART followed by 40 minutes of classroom activities. After analyzing each case, the students participated in small-group discussions to identify and correct the mistakes, thus fostering teamwork and collaboration. Subsequently, one representative student from each group shared their answers and the investigator summarized the class and addressed any questions that arose during the discussions in the final 10 minutes.

Conventional lecture-based technique

The students in group B attended a 50-minute didactic lecture followed by an additional 10 minutes for questions. No scheduled discussion time was provided during or after the class, and there were no elements of active learning included in this approach.

Post-intervention phase

Following the intervention, both groups of students were provided with the same questionnaire. Additionally, they completed an anonymous survey questionnaire to assess their perceptions of the teaching methods. Knowledge retention was evaluated by readministering the questionnaire after a 4-week interval. Figure 1 shows a CONSORT flow diagram detailing the study's design.

Statistical analysis

Data obtained were entered in Microsoft Excel (2020) and analyzed using the IBM Corp. Released 2012. IBM SPSS® (Statistics for Windows, version 21.0. Armonk, NY: IBM Corp.) The normality of the data distribution was assessed using the Shapiro–Wilk test, and it was found to be normally distributed. Pearson's Chi-square test was applied to compare the gender and age disparities between the two groups. The independent-sample *t*-test was used to compare knowledge scores between the groups. The repeated-measures analysis of variance (ANOVA) was employed for pairwise comparison of knowledge at baseline, post-intervention, and after 4 weeks within the respective groups. The survey questionnaire scores were categorized into five grades, considering a score of ≥ 4 as satisfactory, and the Chi-square test was employed to compare the satisfactory scores between the two groups. A significance level of $P \leq 0.05$ was chosen to determine statistical significance.

Results

Among the 74 students in this study, 18 were males and 56 were females with a mean age of 21.64 ± 0.48 years [Table 1]. There were no dropouts, and all students completed the follow-up assessment.

Knowledge among students

Table 2 presents the mean knowledge score among students of the two groups at three time intervals: baseline, post-intervention, and after 4 weeks. There was no statistically significant difference in the mean knowledge of the students in the baseline test among both groups, indicating their knowledge to be similar at baseline ($P = 0.368$). After the intervention, mean

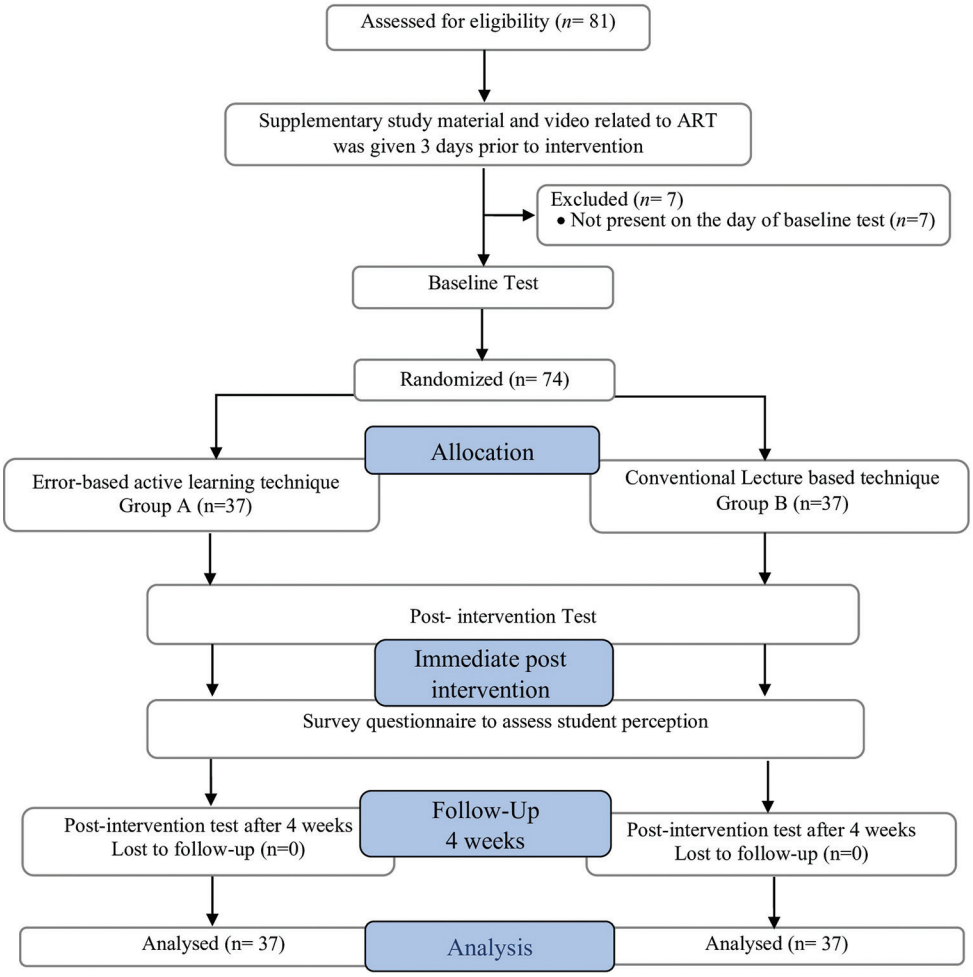

Figure 1: Consolidated Standards of Reporting Trials (CONSORT) diagram

Table 1: Descriptive statistics of demographic details

Characteristics	Error-based active learning *n* (%)	Lecture-based learning *n* (%)	Chi-square /*F*	*P*
Gender†				
Male	6 (16.2%)	12 (32.4%)	2.643	0.104
Female	31 (83.8%)	25 (67.6%)		
Total	37 (100%)	37 (100%)		
Age in years‡				
Mean±SD	21.68±0.48	21.59±0.50	0.525	0.469

All values are expressed as the frequency with percentages (in parentheses) and mean±standard deviation (SD). The statistical test used: †Chi-square test, ‡Unpaired *t*-test; level of significance: $P \leq 0.05$ is considered a statistically significant association

Table 2: Comparison of knowledge scores in the error based active learning and lecture based groups at different time intervals

Group (*n*=37)	Baseline	Post-intervention	Four weeks	*F*	*P*‡
Error-based active learning					
Mean±SD	13.78±3.60$^{a\alpha}$	20.92±1.42$^{a\beta}$	18.30±2.02$^{a\gamma}$	70.72	0.000**
95% CI	12.56-15.00	20.44–21.39	17.62–18.97		
Lecture-based learning					
Mean±SD	13.08±2.97$^{a\alpha}$	16.97±3.06$^{b\beta}$	14.05±4.26$^{b\alpha}$	34.63	0.000**
95% CI	12.08–14.07	15.95–17.99	12.63–15.47		
t	0.906	7.09	5.46		
P†	0.368	0.000**	0.000**		

Different lower case (small letters a and b) indicates a significant difference between the groups within the same column. The statistical test used: †Unpaired *t*-test. Different Greek symbols (α, β, and γ) indicate a significant difference within the group at various time intervals (in the row). The statistical test used: Dunn's *post hoc* method following a significant ‡repeated-measures ANOVA test. Level of significance: *$P \leq 0.001$ is considered highly statistically significant

knowledge increased from baseline to post-intervention in both groups [Figure 2]. However, group A performed significantly better in the post-intervention test than group B ($P = 0.000$). When mean knowledge was assessed after 4 weeks, there was a substantial reduction in both groups; however, group A had better knowledge retention than group B ($P = 0.000$).

When pairwise data were considered, the mean knowledge score at the three time intervals demonstrated a statistically significant difference in both groups ($P = 0.000$). Post hoc test revealed a significant difference in the knowledge scores at three time intervals of group A ($P = 0.000$); however, the differences were not significant at baseline and after 4 weeks in group B ($P = 0.167$).

Perception among students

Table 3 presents the perception of students on the teaching methods. There were 74 valid responses, giving a response rate of 100%. The majority (95%) of the students in group A found the approach to be efficient, compared to group B (76%) ($P = 0.022$). Similarly, 91.8% of students in group A were of the opinion that the teaching method improved their clinical and problem-solving skills compared to 56.75% in group B ($P = 0.000$). Group A demonstrated higher satisfaction in the majority of the items compared to group B except for extracurricular workload ($P = 0.06$).

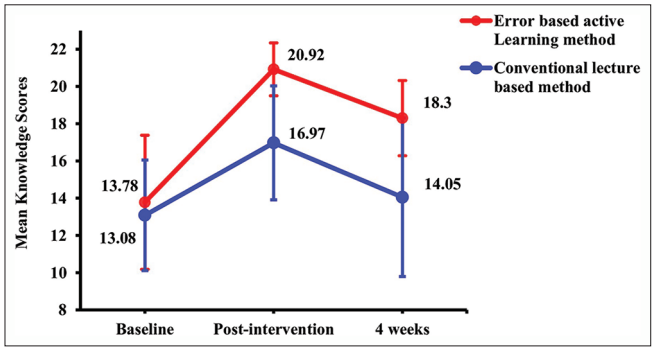

Figure 2: Knowledge scores of error-based active learning and convention lecture-based group at baseline, post-intervention, and after 4 weeks

Discussion

Student-centered learning revolves around innovative teaching approaches that treat students as active participants nurturing essential skills such as problem-solving and critical thinking.[21] This study aimed to assess the effectiveness of error-based active learning in enhancing the knowledge of final-year undergraduate dental students. This is particularly relevant given the recent adoption of student-centered learning.[22] The study is the first of its kind to explore the combined use of CBL and MDL approaches in dental education.

CBL requires students to have a foundational understanding of the topic to engage in meaningful case discussions.[23] In this study, we ensured that students were well-prepared by providing them with background knowledge on the subject of ART through a video and reading material. It is worth noting that both groups received these preparatory materials ensuring comparable baseline knowledge. In this study, the mean post-intervention test scores of both groups were higher than the baseline test scores. Furthermore, in the post-intervention test, the error-based active learning group outperformed the lecture-based group. Sangam *et al*. and Du *et al*. discovered similar results when the CBL model was implemented alone, with the post-session test scores significantly higher in the CBL group compared to the lecture-based group.[24,25] In a pre-/post-study by Shigli *et al*., a significant increase in post-test knowledge score was found, concluding CBL to be an effective approach for improving the knowledge of dental interns.[26]

In contrast, a few studies have yielded different results, indicating that the lecture-based method was more advantageous in terms of effectiveness when compared

Table 3: Opinions on the error-based active learning and the lecture-based method

Items surveyed	Satisfaction scores(%)		Chi-square	*P*-value
	Error-based active learning (*n*=37)	Lecture-based learning (*n*=37)		
I like this approach	89.19	72.97	3.171	0.07
This approach is efficient	94.59	75.68	5.232	0.022*
This approach decreases extracurricular work	45.9	67.6	3.52	0.060
This approach makes learning more targeted and more interesting	94.59	86.49	1.42	0.233
This approach enhances my ability to analyze and solve problems	91.89	56.76	11.96	0.001**
This approach helps me master theoretical knowledge	94.6	89.2	0.725	0.394
This approach helps me improve my clinical skills	92	48.65	16.55	0.000**
I would recommend this learning method to other topics also	86.5	83.8	0.107	0.744
This model emphasizes more on teamwork	97.3	10.81	55.71	0.000**

All values are expressed as percentage. The statistical test used: Chi-square test; level of significance: *P 0.05 is considered a statistically significant association. **$P \leq 0.001$ is considered highly statistically significant

to CBL[27,28] and few with no difference between the two methods.[29] These discrepancies were attributed to the introduction of a new teaching methodology and variations in the knowledge assessment between the groups. These studies employed factual multiple-choice questionnaires for the lecture-based learning group and cognitive skill-based questionnaires for the CBL group, which might have given the lecture-based group an advantage. However, in this study, knowledge was evaluated using a comprehensive questionnaire that encompassed both theoretical and cognitive skill-based questions, ensuring a more balanced assessment.

The findings of this study revealed that the error-based active learning group demonstrated superior knowledge scores compared to the lecture-based group after a 4-week period, indicating that the former group exhibited better knowledge retention of the topic. This observation aligns with previous studies conducted by Sangam *et al*. in Anatomy,[24] Rustagi *et al*. in Anatomy,[30] and Singhal *et al*. in Microbiology,[31] all of which found that the group utilizing CBL exhibited a greater mean difference between post-session and retention test scores. These findings suggest that the implementation of any active learning method can foster deeper, self-driven learning experience leading to enhanced retention of acquired knowledge. Furthermore, it is well-documented in the literature that a significant amount of forgetting occurs within the first 4 weeks with retention rates progressively decreasing thereafter.[32] This rationale underpins the selection of a 4-week interval for evaluating knowledge retention frame in this study.

Several recent studies have explored the benefits of combining various active learning methods to enhance student outcomes. Lin *et al*. explored the integration of team-based learning and CBL in the teaching of dental materials' science topics and found that students had a positive perception toward this approach, citing its effectiveness in fostering teamwork and facilitating group discussions.[33] Similarly, Liu *et al*. combined CBL and problem-based learning (PBL) to teach maxillary sinus floor augmentation and concluded that the combined approach resulted in better academic knowledge, enhanced case analysis skills, and increased student satisfaction when compared to traditional teacher-centered approaches.[11] Ginzburg *et al*. utilized a combined PBL-CBL approach to engage medical students in exploring the subject of cost-related challenges in health care and found it to be effective.[34] Additionally, Hu *et al*. integrated the flipped classroom model with PBL in a hyperthyroidism module resulting in improved performance, despite the increased workload for students.[10] This study is consistent with these findings, suggesting that combining different methods can enhance student performance.

The students' opinion is crucial in evaluating new teaching methods. Over 90% of students reported that the combined method improved their learning experience, problem-solving ability, clinical skills, theoretical knowledge, and teamwork awareness. Similar results were observed in other studies in which combined active learning methods were applied in implant dentistry,[11] leadership training,[34] and biochemistry experiment teaching.[8] This positive perception was likely due to the novelty of the teaching approach, which encourages student participation and input.

Limitations and future recommendations

This study evaluated the short-term outcomes of the combined method involving CBL and MDL among final-year dental undergraduate students at the beginning of their academic year. While the findings offer valuable insights such as knowledge acquisition and retention, further research is needed to understand the long-term sustainability and applicability across larger and diverse student populations. The academic ranking of the students was not considered in this study given the recent commencement of new academic year. However, both groups received preparatory materials to ensure comparable baseline knowledge. Future studies should incorporate academic ranking for a more comprehensive analysis.

Error-based learning can place greater demands on instructors escalating their teaching workload. Alongside creating teaching materials, instructors must also devise study materials, case scenarios with series of mistakes, and pre-test questionnaires. To tackle this challenge, a well-coordinated teaching team can be established in which instructors collaborate closely, sharing tasks such as case scenario creation and questionnaire development.

Despite the increased extracurricular workload, optimizing the approach can make learning enjoyable. Professional bodies can consider integrating error-based active learning into curricula and conducting faculty training programs to encourage diverse teaching methods and stimulate higher order thinking in students.

Conclusion

The error-based active learning method proved to be more effective than the lecture-based method in the context of ART. Engaging students through active learning not only stimulates their interest but also improves evidence-based education and clinical practice. Additionally, exposure to different teaching methods expands students' learning experiences, facilitating critical thinking and nurturing cognitive flexibility.

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There are no conflicts of interest.

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