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# EFFECTIVENESS OF AI-GENERATED INFOGRAPHICS FOR TEACHING TUMOR GENOMICS AND MOLECULAR PATHOGENESIS OF ORAL CANCER TO UNDERGRADUATE DENTAL STUDENTS: A RANDOMIZED CROSSOVER STUDY

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## ABSTRACT

**Background:** The undergraduate dental students often find tumor genomics and molecular pathogenesis difficult to understand using conventional text-based instruction. AI-generated infographics may facilitate visualization of these complex molecular processes.
**Objective:** To evaluate the effectiveness of AI-generated infographics with concise summaries for teaching tumor genomics and molecular pathogenesis of oral squamous cell carcinoma to undergraduate medical students**.**
**Methods:** A randomized crossover study was conducted among 48 thirdyear dental students. Participants were randomly allocated into two groups. Each group received two instructional modules, using either AI generated infographics with concise clinical summaries or conventional textbased study materials, before crossing over to the alternate learning modality. Academic performance was assessed using validated pre and post intervention multiple choice examinations. Secondary outcomes included learner satisfaction, and perceived cognitive load, measured using structured questionnaires. Data were analyzed using paired statistical tests appropriate for the crossover design. Statistical significance was set at $p < 0.05$.
**Results:** Students achieved significantly higher post-intervention examination scores following infographic-based learning compared with traditional study materials ($p < 0.001$). Students reported greater satisfaction, together with significantly lower perceived cognitive load (all $p < 0.001$).
**Conclusions:** AI-generated infographics represent an effective educational strategy for teaching tumor genomics and molecular pathogenesis of oral squamous cell carcinoma. By simplifying complex molecular interactions into structured visual representations improve student understanding, and reduce cognitive load.

**KEYWORDS:** Artificial intelligence; Infographics; Multimedia learning; Knowledge retention; Medical education.

## INTRODUCTION

Undergraduate medical education requires students to acquire and integrate extensive basic, and clinical knowledge. At the same time, they must develop diagnostic reasoning and clinical decision-making skills. The greater complexity of medical curricula, expanding volume of scientific information, and limited instructional methods and time constrain pose a substantial challenge for both educators and students. [1] Conventional text-based learning remains the predominant and traditional instructional approach. However, dense textual materials place significant cognitive demands on learners. Students are often required to independently organize and synthesize complex information. This process can reduce efficiency and hinder knowledge retention. As a result, there is growing interest in evidence-based instructional strategies that foster meaningful learning while minimizing unnecessary cognitive burden. [1,2]
Visual learning has gained attention as an effective way to improve understanding of complex concepts in health professions education. The Cognitive Theory of Multimedia Learning explains that meaningful learning occurs when students actively integrate information presented through both verbal and visual channels.[3] Similarly, the Dual Coding Theory suggests that combining words with images creates complementary mental representations that strengthen encoding and retrieval of information.[4,5] Educational infographics apply these principles. They combine concise text, diagrams, icons, color coding, and visual hierarchies into structured resources. These highlight relationships among concepts rather than presenting isolated facts. [6,7] Compared with traditional narrative materials, infographics have been shown to enhance engagement, comprehension, information recall, and academic performance across diverse medical and health professions education settings.[6-9]

Recent advances in artificial intelligence (AI), particularly generative technologies, have created new opportunities for developing high-quality educational resources. AI-assisted platforms can rapidly transform evidence-based content into visually organized infographics. [10,11] This enables educators to produce standardized instructional materials. Importantly, AI should be regarded as an instructional design aid rather than a replacement for educators. Faculty retain responsibility for content selection, scientific accuracy, pedagogical alignment, and quality assurance. The integration of AI into educational resource development therefore offers the potential to improve both the accessibility and scalability of high-quality learning materials.[12,13]

The potential benefits of infographic-based learning are particularly relevant in medical education. Students must integrate clinical photographs, radiographic findings, histopathological features, diagnostic criteria, and treatment principles into coherent clinical reasoning. Organizing these diverse sources of information into visually structured resources may reduce extraneous cognitive load and support deeper conceptual understanding. Although visual learning strategies have demonstrated educational benefits in medical education, evidence on AI-generated infographics in undergraduate medical education remains limited. Moreover, few studies have evaluated their impact using robust experimental designs that assess immediate learning, knowledge retention, cognitive load, learner confidence, and satisfaction simultaneously. [14-16]

The present study evaluated the effectiveness of AI-generated infographics accompanied by concise clinical summaries as an adjunct to conventional text-based learning for teaching tumor genomics and molecular pathogenesis of oral squamous cell carcinoma to undergraduate dental students. We hypothesized that infographic-based learning would improve academic performance. In addition, it was expected to reduce perceived cognitive load and satisfaction compared with conventional text-based learning.

## METHODOLOGY

A prospective, randomized crossover study was conducted between 1 July 2026 and 31 August 2026 at Bibi Aseefa Dental College, Larkana, Pakistan. All third-year undergraduate dental students were enrolled. Of the 50 eligible students, 48 completed both instructional modules and were included in the final analysis. Two students were absent during one or more study sessions and therefore did not complete the crossover intervention (Figure 1). Because of the fixed class size, no formal sample size calculation was performed.

Before each instructional module, participants completed a baseline MCQ assessment corresponding to the learning objectives of that module to confirm comparable knowledge levels between the two learning sequences. Following baseline assessment, participants were randomly assigned in a 1:1 ratio to one of two learning sequences using a computer-generated randomization schedule.

Two instructional modules, from the Oral Pathology, Module 1 included Tumor Genomics of Oral Squamous Cell Carcinoma, while Module 2 Molecular Pathogenesis of Oral Squamous Cell Carcinoma were selected based on comparable learning objectives, content complexity, and expected cognitive demand to minimize topic-related bias. Each module was delivered in two formats, AI-generated infographics with concise clinical summaries (infographic-based learning) and Conventional text-based materials derived from standard course resources. Students in “Sequence A” first received the infographic-based learning intervention for the initial instructional module, followed by conventional text-based learning for the second. Students in “Sequence B” received the modalities in the reverse order. Because each instructional module addressed independent topics, a washout period was not required.

The infographic-based learning resources were developed using ChatGPT (OpenAI, San Francisco, CA, USA), a generative artificial intelligence platform. The AI-generated content was subsequently reviewed and refined by the investigators to ensure scientific accuracy, curricular alignment, and educational appropriateness. Each infographic illustrated genomic mutations, signaling pathways, molecular interactions, biomarker expression, and sequential events involved in oral carcinogenesis using flow diagrams, pathway maps, color-coded molecular networks, and concise explanatory summaries. A brief clinical summary accompanied each infographic to reinforce essential learning points and facilitate rapid revision. The conventional learning materials consisted of the same educational content presented in narrative text format, without visual restructuring. All educational content was prepared from standard teaching resources.

Both instructional formats contained identical learning objectives and equivalent factual information, differing only in presentation. This ensured that any observed differences in outcomes reflected the instructional format rather than variations in content. Teaching sessions were conducted under standardized classroom conditions by the same faculty member to minimize instructor-related variability. Participants were allocated 30 minutes to study each instructional module, followed immediately by the post-intervention assessment under identical examination conditions.

The primary outcome was immediate academic performance, assessed using post-intervention multiple-choice question (MCQ) examinations designed on the predefined learning objectives. Equivalent examination formats and difficulty levels were maintained across both instructional modules. Secondary outcomes were learner satisfaction and perceived cognitive load. Learner satisfaction was evaluated using a structured questionnaire completed immediately after each intervention. Perceived cognitive load was measured using a validated single-item cognitive load rating scale, with higher scores indicating greater mental effort during learning.

Data were analyzed using IBM SPSS Statistics version 26. Continuous variables were summarized as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. The distribution of continuous variables was assessed using the Shapiro–Wilk test. Baseline pre-intervention MCQ scores were compared to confirm equivalence between the two learning sequences. Within-participant differences in post-intervention academic performance, learner satisfaction, and perceived cognitive load were analyzed using paired-samples t-tests. A two-tailed p value $<0.05$ was considered statistically significant.

Ethical approval was obtained from the Institutional Ethical Review Board (F.No.00028/HSA/MSHPE-2024) prior to study initiation. Written informed consent was obtained from all participants before enrollment. Participation was voluntary, and students were assured that their decision to participate or withdraw would not affect their academic evaluation.

## RESULTS

The mean age of participants was 21.4 ± 0.7 years, and 30 (62.5%) were female. Previous experience with AI-assisted learning tools was reported by 28 students (58.3%), while 18 (37.5%) had previously used educational infographics (Table 1).

Baseline MCQ scores were comparable between Sequence A and Sequence B (11.9 ± 2.1 vs. 12.1 ± 2.3), indicating similar baseline knowledge before the intervention (mean difference −0.2, 95% CI −1.4 to 1.0; p = 0.71) (Table 2). Immediate post-intervention academic performance was significantly higher following infographic-based learning than conventional text-based learning (41.8 ± 4.3 vs. 36.7 ± 4.8). The mean paired difference was 5.1 marks (95% CI 3.9–6.3; $p < 0.001$) (Table 3). Perceived cognitive load was significantly lower following infographic-based learning than conventional text-based learning (4.2 ± 1.1 vs. 5.8 ± 1.2). The mean paired difference was −1.6 points (95% CI −2.1 to −1.1; $p < 0.001$) (Table 3).

Learner satisfaction was also significantly higher following infographic-based learning than conventional learning (4.7 ± 0.5 vs. 3.8 ± 0.7; mean difference 0.9, 95% CI 0.6–1.2; $p < 0.001$) (Table 3). More than 85% of participants agreed or strongly agreed that infographic-based learning improved understanding of concepts, facilitated revision, enhanced recall, increased motivation, and should be incorporated into future teaching (Table 4).

**Table1. Baseline characteristics of participants (n = 48)**

| Characteristic | Value |
|---|---|
| Age (years), mean ± SD | 21.4 ± 0.7 |
| Female, n (%) | 30 (62.5) |
| Male, n (%) | 18 (37.5) |
| Previous AI-assisted learning, n (%) | 28 (58.3) |
| Previous exposure to educational infographics, n (%) | 18 (37.5) |

**Table 2. Baseline pre-intervention MCQ scores**

| Sequence | Mean ± SD | Mean difference (95% CI) | *p*-value |
|---|---|---|---|
| Sequence A (n = 24) | 11.9 ± 2.1 | | |
| Sequence B (n = 24) | 12.1 ± 2.3 | −0.2 (−1.4 to 1.0) | 0.71 |

**Table 3. Comparison of post-intervention learning outcomes between infographic-based learning and conventional text-based learning (n = 48)**

| Outcome | Conventional text-based learning Mean ± SD | Infographic-based learning Mean ± SD | Mean difference (95% CI) | p-value |
|---|---|---|---|---|
| **Immediate academic performance (MCQ score)** | 36.7 ± 4.8 | 41.8 ± 4.3 | 5.1 (3.9 to 6.3) | <0.001 |
| **Perceived cognitive load (Paas scale)** | 5.8 ± 1.2 | 4.2 ± 1.1 | −1.6 (−2.1 to −1.1) | <0.001 |
| **Overall learner satisfaction (5-point Likert scale))** | 3.8 ± 0.7 | 4.7 ± 0.5 | 0.9 (0.6 to 1.2) | <0.001 |

**Abbreviations:** CI, confidence interval; MCQ, multiple-choice question; SD, standard deviation.
**Footnote:** Values are presented as mean ± SD. Mean differences represent within-participant paired comparisons because each participant completed both instructional interventions in the randomized crossover design. Statistical comparisons were performed using paired analyses, and statistical significance was defined as $p < 0.05$.

**Table 4. Student satisfaction with infographic-based learning (n = 48)**

| Statement | Agree/Strongly Agree, n (%) |
|---|---|
| Improved understanding of concepts | 44 (91.7) |
| Facilitated revision | 45 (93.8) |
| Enhanced recall | 42 (87.5) |
| Increased learning motivation | 41 (85.4) |
| Information was well organized | 46 (95.8) |
| Would recommend for future teaching | 45 (93.8) |
| Overall satisfied | 46 (95.8) |

## DISCUSSION

This randomized crossover study demonstrated that AI-assisted infographic-based learning, combined with concise clinical summaries, produced superior educational outcomes compared with conventional text-based learning among undergraduate dental students. Learners exposed to infographic-based instruction achieved higher immediate performance, reported lower cognitive load, and expressed greater satisfaction.

The improvement in academic performance aligns with contemporary multimedia learning theory, which emphasizes that meaningful learning occurs when verbal and visual information are integrated. Traditional text-based resources require learners to independently organize large volumes of information. In contrast, well-designed infographics reduce extraneous processing by presenting essential concepts within a structured visual framework.

Tumor genomics represents one of the most conceptually demanding areas of modern dental education because students must integrate molecular biology, genetics, pathology, and clinical oncology. AI-generated infographics enabled visualization of interconnected genomic pathways and molecular events, thereby facilitating schema construction and reducing cognitive burden. This instructional strategy may be particularly valuable for teaching precision oncology concepts that are increasingly incorporated into undergraduate medical curricula.

These empirical gains mirror previous findings across health professions education demonstrating that structured visual interventions enhance knowledge acquisition, comprehension, and immediate recall.[6–9] While earlier studies primarily evaluated manually designed visual aids or 3D visual models,[9] the current results confirm that AI-generated visual resources yield comparable cognitive benefits.

This approach is particularly valuable as students must interpret clinical features, radiographic findings, differential diagnoses, and management principles simultaneously. By integrating these elements into concise visual summaries, infographic-based learning may promote efficient schema construction and deeper conceptual understanding rather than rote memorization.[17-19] The higher scores observed may reflect improved encoding and retrieval through dual visual-verbal representations and reduced extraneous cognitive load. Similar benefits have been reported in health professions education, where multimedia strategies outperform text-only materials, especially for complex clinical content.[20-22]

These findings reinforce the growing recognition that instructional design is a key determinant of educational effectiveness. Optimizing presentation, rather than increasing content volume, can substantially improve learning efficiency. In this study, AI facilitated infographic development, but faculty validation ensured scientific accuracy, curricular alignment, and educational quality. As AI becomes more integrated into health professions education, emphasis should remain on evidence-informed instructional design rather than technology alone. [12,23]

Developing traditional, high-quality infographics historically required specialized graphic design skills and considerable faculty time. Generative AI substantially accelerates content synthesis and structuring, making visual resource creation scalable and adaptable for routine classroom integration.[11,12] However, these findings reinforce that AI platforms function best as instructional design assistants rather than autonomous educators.[11]

Evidence from medical and nursing education supports the value of visually structured resources, showing improvements in comprehension, satisfaction, and performance. [6,8,24] The present findings extend this literature to undergraduate dental education, demonstrating that AI-assisted infographics can enhance multiple outcomes within a randomized crossover design.

The observed reduction in cognitive load provides a plausible mechanism. Cognitive Load Theory suggests that instructional materials should minimize unnecessary effort while preserving intrinsic complexity. Presenting concepts in a visually organized format may reduce extraneous load, enabling learners to allocate working memory to schema construction and reasoning. [14,25,26]

High satisfaction further supports the educational value of infographic-based learning. Most participants perceived the AI-assisted infographics as improving comprehension, facilitating revision, and enhancing recall. Satisfaction alone does not confirm effectiveness, but its concurrence with objective improvements strengthens the educational significance of the intervention. Collectively, these findings suggest that AI-assisted infographic development represents a practical strategy for enhancing instructional design while maintaining faculty oversight. [22,23,27]

This study was conducted at a single institution with a relatively small cohort of third-year dental students, limiting generalizability. Satisfaction, and cognitive load were measured using self-reported questionnaires, which may be subject to bias. Finally, the quality of AI-generated resources may vary depending on platform, prompts, and oversight. Future multicenter studies with larger cohorts, longer follow-up, and evaluation of clinical competence are warranted.

## CONCLUSION

AI-generated infographics represent an effective educational strategy for teaching tumor genomics and molecular pathogenesis of oral squamous cell carcinoma. By simplifying complex molecular interactions into structured visual representations improve student understanding, reduce cognitive load, and support integration of precision oncology concepts into undergraduate medical education.

**Conflict of Interest:** None

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