

Effectiveness of Computer Assisted Learning Program among Undergraduate Bachelor of Dental Surgery Students in Learning Oral Potentially Malignant Disorders

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Abstract

Background

Computer Assisted Learning Program (CALP) use digital technologies to facilitate interactive, learner-centered instruction. In dental education, CAL supports self-directed learning and enhances understanding of complex clinical conditions. Oral Potentially Malignant Disorders (OPMDs) represent a significant public health concern. Given their potential for malignant transformation, improving undergraduate dental students' competency in recognizing and managing OPMDs is essential. This study aimed to assess the effectiveness of the CALP in enhancing knowledge acquisition and retention related to OPMDs among undergraduate dental students.

Methods

A mixed-methods study was conducted among 41 fourth year (VII-semester) dental students. Baseline knowledge was assessed with a pre-test before implementation of the CALP. The intervention included structured CAL modules followed by two Case Based Discussions (CBD) designed to reinforce clinical application. A post-test was conducted one week after the CBDs, and a follow-up test was administered three months later to assess knowledge retention. Quantitative data were analyzed using descriptive statistics to compare mean scores across time points. Qualitative data were collected through focus group discussion (FGD) involving faculty and students. These discussions were audio-recorded, transcribed verbatim and analyzed using thematic analysis to explore participants' perceptions of the CALP.

Results

Mean scores (maximum score 50) improved from 38.22 ± 4.04 in pre-test to 45.21 ± 2.69 in post-test, and further to 47.13 ± 3.39 at three-month follow up. Improvements between pre-test and post-test and between post-test and follow-up were statistically significant ($p < 0.001$ and $p = 0.008$ respectively), indicating immediate learning gains and sustained knowledge retention. Qualitative analysis identified key themes: enhanced integration of theoretical knowledge with clinical presentation, improved diagnostic reasoning, and greater motivation for self-directed learning. Participants highlighted the value of interactive modules, and case-based discussions in deepening their understanding of OPMDs. Faculty also noted improved student participation and critical thinking during discussions.

Conclusion

The computer-assisted learning program significantly improved knowledge acquisition and long-term retention related to OPMDs among undergraduate dental students. Positive perceptions expressed by

both students and faculty underscore the program's potential as a valuable adjunct to traditional teaching methods. Incorporating CALP into undergraduate curricula may enhance clinical competence and promote active, self-directed learning in dental education.

Background

Computer Assisted Learning Program (CALP) refers to educational processes and learning environments facilitated using computers, enabling interactive and learner-centered instruction.¹ It is also described in the literature as Computer Based Instruction (CBI), Computer Aided Learning (CAL), or Computer Aided Instruction (CAI). Advances in computing technology and the widespread availability of the internet over recent decades have enabled the development of reliable, cost effective and highly interactive learning environments, thereby transforming educational practices globally.¹

CALP was first introduced into dental education in 1971, at the University of Kentucky, marking one of the earliest uses of computers as instructional tools in dental curriculum. Since then, a growing body of evidence has demonstrated that students exposed to CALP achieve learning outcomes comparable to or in some cases better than those taught exclusively through traditional methods.² CALP offers several advantages, including flexibility, time efficiency, increased learner motivation, and enhanced learner engagement.^{2,3} It has also been shown to improve students' confidence, particularly in clinical diagnosis.⁴

A key strength of CALP lies in its ability to integrate multiple forms of media, including text, two-dimensional and three-dimensional images, videos, animations, audio, combined with learner-controlled interactions.¹ Many CALPs are designed based on the principles of the Problem Based Learning (PBL) and Case Based Learning (CBL), thereby promoting active learning and clinical reasoning and decision making skills.¹ Such programs have been widely adopted across dental disciplines, including orthodontics, prosthodontics, periodontology, and endodontics.^{1,2} Additionally, computer-assisted simulation has become an important modality in preclinical dental education, allowing students to develop procedural skills in a safe and controlled environment.⁵

Despite increasing integration of CALP into dental curricula, gaps remain in students' clinical competence, particularly in the diagnosis of oral cancer and Oral Potentially Malignant Disorders (OPMDs). While theoretical knowledge tends to improve with advancing years of training, diagnostic accuracy and clinical reasoning do not always progress proportionally.⁶ Conventional classroom-based teaching alone may be insufficient to develop the pattern-recognition and decision-making skills required to diagnose OPMDs, which often present with subtle and diverse clinical features.² Students frequently report difficulty in differentiating normal oral mucosal variants from early manifestations of OPMDs, compounded by limited clinical exposure to these patients.² Effective clinical management of such conditions requires not only sound theoretical knowledge but also critical thinking and diagnostic skills.

OPMDs are defined as any oral mucosal abnormality that are associated with a statistically increased risk of developing oral cancer.⁷ Common examples include erythroplakia, leukoplakia, oral submucous fibrosis (OSF) and oral lichen planus (OLP), although several other conditions may also carry a risk of progression to oral cancer.⁸ Clinically, early oral cancer may present as a non-healing ulcer, persistent lump or red, white or mixed lesions, and is preceded by detectable OPMDs.^{9,10} Early identification and management of these conditions are therefore critical in reducing morbidity and mortality associated with oral cancer.

OPMDs represent a significant public health burden, particularly in Asian regions where preventable risk factors such as tobacco and betel quid use are highly prevalent.¹¹ The widespread availability of smokeless tobacco products, often marketed aggressively and sold in inexpensive sachets, has contributed to increased use among younger populations. These practices are strongly associated with the development of OPMDs and subsequent progression to oral cancer.¹¹ In Nepal, the Demographic and Health Survey (2016), reported tobacco use prevalence of 52.3% among males and 8.4% among females, indicating a substantial population at risk for OPMDs.¹²

Previous studies have explored the effectiveness of CALP in dental education. Early work by Wenzel et al. demonstrated the utility of adaptive, feedback driven CALP in teaching intraoral radiographic techniques.¹³ Hobson et al. reported significant knowledge gains using both CALP and traditional teaching methods in orthodontics.¹⁴ More recently, studies have emphasized the need for improved training in the detection and management of OPMDs, particularly in communication and patient counselling.¹⁵ Hassona et al. further demonstrated that diagnostic ability in oral cancer and OPMDs is positively correlated with knowledge level, reinforcing the importance of effective educational interventions.¹⁶

The COVID-19 pandemic further accelerated the adopting of digital learning strategies, as conventional face-to-face teaching was disrupted worldwide.⁶ CALP emerged as practical and effective alternatives, enabling case-based discussions and interactive learning while maintaining educational continuity. These approaches provided valuable opportunities to enhance students' understanding of OPMDs, even in absence of direct clinical exposure.⁶ Inadequate knowledge and diagnostic practices among healthcare professionals contribute to delays in the diagnosis of oral cancer.⁶ Dental practitioners are often the first point of contact for patients with oral lesions and are therefore ideally positioned to perform opportunistic screening, provide risk factor counselling, and initiate timely referrals.¹⁷ Ensuring that undergraduate dental students develop competence in recognizing early signs of OPMDs and oral cancer is therefore essential.

Given the high disease burden of OPMDs, the limitations of traditional teaching methods, and the increasing role of digital education, there is a clear need to evaluate innovative instructional approaches. This study aimed to assess the effectiveness of effectiveness of computer-assisted learning programs

in enhancing knowledge acquisition, diagnostic understanding, and retention related to OPMDs among undergraduate dental students.

Methods

Study design, aim and setting

This mixed-methods study comprised a quasi-experimental quantitative component and a qualitative component. The quantitative arm employed a single group pre-test- post-test design with a three-month follow-up to assess knowledge acquisition and retention. The qualitative arm used focus group discussion (FGD) with thematic analysis to explore students' perceptions of the intervention. The study was conducted at the College of Dental Surgery, B. P. Koirala Institute of Health Sciences (BPKIHS), Dharan, Nepal, from July 2021 to March 2022.

Participants and recruitment

All fourth year (VII semester) Bachelor of Dental Surgery (BDS) students enrolled at the College of Dental Surgery, BPKIHS were invited to participate using complete enumeration sampling. Students were eligible if they provided written informed consent and were able to attend all scheduled assessments. Those who did not provide consent or were unable to complete all assessments were excluded from the study.

Intervention: Computer Assisted Learning Program (CALP)

The CALP intervention consisted of two synchronous, online case-based discussion (CBDs) sessions delivered via Zoom® platform. The sessions were designed to promote active learning, clinical reasoning, and diagnostic decision-making. Each session involved structured discussion of authentic clinical cases representing common presentations of OPMDs: (1) a predominantly white lesion (oral leukoplakia) and (2) a mixed red and white lesion (oral lichen planus). The CALP materials included high-quality clinical images and relevant patient histories necessary for clinical interpretation and diagnosis. Students participated using personal electronic devices (laptops or equivalent) with internet connectivity. Facilitated discussion encouraged learners to analyze clinical features, formulate differential diagnoses, and justify their reasoning.

Quantitative assessment and outcome measures

Knowledge related to diagnosis of OPMDs was assessed using 50-item multiple-choice questions (MCQs). The instrument was developed by subject experts and underwent face and content-validation by faculty members from the Department of Oral Medicine and Radiology. The same MCQ instrument was administered at three points:

1. Pre-CALP test (baseline): prior to the CALP intervention.
2. Post-CALP test: one week after completion of the CALP.

3. Retention test: three months after completion of the CALP.

All questions were compulsory, and no negative marking was applied. The primary outcome was the change in mean scores between pre-test and post-test for knowledge acquisition, and between post-test and three-month follow-up for knowledge retention.

Qualitative component: focus group discussion

A subset of students was invited to participate voluntarily in a focus group discussion (FGD) to explore their perceptions and experiences of CALP. Thirteen students participated in the FGD. The discussion was conducted in English via Google Meet, lasted approximately 60 minutes, and was audio-recorded with participants' consent. A semi-structured interview guide was used to facilitate discussion across key domains including a) perceived usefulness of CALP in understanding OPMDs, b) influence of self-directed learning, c) development of clinical reasoning beyond factual knowledge, and d) suggestions for improvement. The interview guide was developed specifically for this study based on the study objectives and has not been published elsewhere. The English language version of the interview guide is provided as Supplementary File 1.

Audio recordings were transcribed verbatim using automated transcription tools (Google Meet transcript and Scribbl®) and subsequently verified manually against the original recordings to ensure accuracy.

Data management and analysis

Quantitative data was entered into Microsoft Excel and analyzed using SPSS version 11.5. Descriptive statistics, including mean, standard deviations, and proportions were used to summarize participant characteristics. Paired t-tests were performed to compare mean knowledge scores between pre-test and post-test and between post-test and three-month post-test. A p-value of <0.05 was considered statistically significant.

Qualitative data were analyzed using a qualitative descriptive approach with inductive thematic analysis. Two investigators independently reviewed the transcripts to achieve data familiarization, followed by open coding to identify meaningful units of text. Codes were then compared, refined and grouped into broader categories and themes through an iterative process. Discrepancies were resolved through discussion to ensure consistency and credibility. Faculty perspectives obtained through discussion were incorporated to provide triangulation and enhance the depth of interpretation.

Ethics and consent

Ethical approval was obtained from the Institutional Review Committee (IRC), BPKIHS (Ref: 630/077/078-IRC) and the Thesis Protocol Evaluation Committee (Ref: Acd/733/077/078). Written informed consent was obtained from participants prior to data collection. Participation was voluntary, and confidentiality of responses was maintained throughout the study.

Results

A total of 41 seventh-semester BDS students were initially enrolled in the study. However, four participants were excluded due to incomplete data (two missed the pre-test and one missed the post-test and one missed the three-month post-test), resulting in a final sample size of 37 students. Among them, 17 (45.9%) were male and 20 (54.1%) were female with a mean age of 22.89 ± 0.69 years.

The mean pre-test score was 38.22 ± 4.04 . Following the intervention, the mean post-test score increased to 45.21 ± 2.69 in the immediate post-test. This improvement was found to be statistically significant (paired test, $p<0.001$) (Table 1). Furthermore, the mean score at the three-month post-test was 47.13 ± 3.39 , indicating a significant improvement compared to the immediate post test scores (paired t-test, $p=0.008$) (Table 2). Overall, there was a statistically significant improvement in knowledge scores from pre-test to post-test, as well as a sustained and significant improvement at the three-month follow-up.

Table 1: Comparison of difference in pre and post test score of students

Students	Pre-test	Post-test	p value*
	Mean $\pm$ SD	Mean $\pm$ SD	< 0.001
	38.22 $\pm$ 4.04	45.21 $\pm$ 2.69	

*Paired ‘t’ test, $p<0.05$: statistically significant

Table 2: Comparison of difference in post and three-month post test score of students

Students	Post-test	Three-month Post-test	p value*
	Mean $\pm$ SD	Mean $\pm$ SD	
	45.21 $\pm$ 2.69	47.13 $\pm$ 3.39	0.008

*Paired ‘t’ test, $p<0.05$: statistically significant

Qualitative Analysis

Thematic analysis of the data obtained from student focus group discussions (FGDs) generated sub-themes and themes. (Table 3, 4, 5, 6)

The first question, related to understanding of content of OPMDs with CALP, showed an overarching theme of enhanced clinical understanding through authentic and reflective learning through clinical reasoning, authentic visual learning and reflective self-directed learning (Table 3).

Table 3: Responses to the question related to understanding of content of OPMDs

Themes and subthemes	Codes
Theme: Enhanced clinical understanding through authentic and reflective learning	
Sub-theme 1: Improved clinical reasoning and diagnostic reasoning	correlating clinical scenarios with theory Recognising similarities and differences Holistic interpretation of clinical features Attention to comprehensive signs and symptoms Enhanced diagnostic awareness
Sub-theme 2: Authentic learning through visual and case-based learning	Use of real-life clinical images Visual reinforcement of learning Increased realism and authenticity Contextualization of textbook knowledge
Sub-theme 3: Stimulation of self-directed and reflective learning	Identification of personal learning gaps Motivation for independent learning Increased self-awareness of areas needing improvement Reflective learning practices

This theme was supported by three interrelated subthemes where students reported improved ability to differentiate clinically similar OPMDs and increased awareness of their own learning needs.

1. Improved clinical reasoning and diagnostic reasoning

This was evident as students reported an increased ability to correlate clinical scenarios with theoretical knowledge, recognise similarities and differences between OPMDs, and interpret clinical features more holistically. Many participants highlighted greater attention to comprehensive signs and symptoms, contributing to enhanced diagnostic awareness.

2. Authentic learning through visual and case-based learning

This emerged as a key facilitator of understanding, with students valuing the use of real-life clinical images and case scenarios that reinforced learning visually and enabled contextualisation of textbook concepts into clinical practice.

3. Stimulation of self-directed and reflective learning

Students reported recognising their own learning gaps, developing motivation for independent study, and engaging in reflective practices that enhanced self-awareness of areas requiring improvement.

Overall, these findings indicate that the CAL program supported deeper, clinically oriented learning by integrating cognitive, visual and reflective dimensions.

The responses of second question, relating to how CALP helps in becoming a self-directed learner indicated that it significantly supports the development of self-directed and deep learning behaviors among students (Table 4).

Table 4: Responses to a question related to becoming a self-directed learner

Themes and subthemes	Codes
Theme: Development of self-directed and deep learning behaviours through structured feedback and collaborative learning	
Sub-theme1: Activation of self-directed learning through feedback and assessment	Motivation to consult multiple books and references Use of pre-test and post-test as learning diagnostics Identification of knowledge gaps Targeted remediation of weak areas Assessment-driven self-regulation
Sub-theme 2: Reflective learning and self-monitoring	Reflection on areas of weakness Self-awareness of learning needs Intentional improvement strategies Learning autonomy
Sub-theme 3: Adoption of deep learning strategies	Learning in small, manageable chunks In-depth exploration of content Focus on long-term retention Strategic learning approaches
Sub-theme 4: Recognition of the value of team-based learning	Appreciation of collaborative learning Peer-supported knowledge construction Shared problem-solving Learning through discussion

The theme highlighted structured feedback mechanisms functioned as effective diagnostic tools enabling the identification of knowledge gaps and guiding targeted learning. This theme was built based on four subthemes:

1. Activation of self-directed learning through feedback and assessment

Students reported that structured assessments, particularly pre- and post-tests, served as effective diagnostic tools that enabled them to identify knowledge gaps and engage in targeted remediation. This process promoted self-regulation and motivated students to consult multiple resources, reinforcing independent and purposeful learning.

2. Reflective learning and self-monitoring

Students identified enhanced reflective capacity, with increased awareness of their strengths and areas for improvement. They described engaging in intentional strategies to address learning gaps, indicating the development of self-monitoring skills and greater ownership of their learning process.

3. Adoption of deep learning strategies

Students reported a shift towards deep learning approaches, characterized by chunking content into manageable segments, engaging in in-depth exploration, and focusing on long-term retention. These strategies supported a more meaningful understanding of the subject matter beyond surface-level learning.

4. Recognition of the value of team-based learning

Participants acknowledged the importance of collaborative learning, highlighting how peer interaction facilitated shared problem-solving, discussion, and co-construction of knowledge. Team-based learning was perceived as enhancing understanding and enriching the overall learning experience.

Overall, these findings demonstrate that CALP effectively cultivates self-directed, reflective and collaborative learners equipped with deep and sustained understanding.

The third question explored how students felt about the learning outcomes of CALP, beyond content knowledge. The students reported that the CALP facilitated collaborative learning, pedagogical awareness, systematic clinical reasoning, and enhanced communication skills, contributing to broader professional development (Table 5). The theme was elaborated through 4 subthemes:

Table 5: Responses to a question related to any additional learning outcomes along with OPMDs content

Themes and subthemes	Codes
Theme: Development of collaborative, pedagogical and professional competencies beyond disciplinary knowledge	
Sub-theme1: Active group participation and collaborative learning	Active engagement in group discussions Peer interaction and shared learning Exposure to diverse perspectives Collective problem-solving Learner engagement in online learning environment
Sub-theme 2: Exposure to innovative teaching and learning methods	Awareness of innovative pedagogical strategies Use of technology-enhanced learning Transferability of teaching methods to future roles Recognition of innovation as an educational necessity
Sub-theme 3: Development of systematic clinical reasoning	Structured approach to disease management Integration of signs and symptoms Logical sequencing of clinical decision-making Case-based reasoning
Sub-theme 4: Enhancement of communication skills	Increased peer-to-peer interaction Improved articulation of ideas Confidence in discussion and dialogue Communication within group-based learning

1. *Active group participation and collaborative learning*

Students highlighted active engagement in group discussions as a key outcome of the learning experience. Peer interaction facilitated shared learning, exposure to diverse perspectives, and collective problem-solving skills. The online learning environment further supported learner engagement, enabling meaningful collaboration despite virtual settings.

2. *Exposure to innovative teaching and learning methods*

Students reported increased awareness of innovative pedagogical approaches, particularly the use of technology-enhanced learning. They recognized the value of such methods not only for their current learning but also for their potential application in future educational or professional roles, viewing innovation as an essential component of modern education.

3. *Development of systematic clinical reasoning*

The program supported the development of structured clinical reasoning skills, with participants describing a more organized approach to disease management. This included integrating clinical signs and symptoms, applying logical sequencing in decision-making, and engaging in case-based reasoning to enhance diagnostic skills.

4. *Enhancement of communication skills*

Students noted improvements in communication skills, particularly through improved peer-to-peer interaction. They reported greater confidence in articulating ideas, engaging in discussions, and contributing meaningfully within team-based learning contexts

Overall, these findings suggest that the program fostered a range of collaborative, pedagogical, and professional competencies that extend beyond disciplinary knowledge.

In the final question, relating to ways to make CALP more effective, students identified technological limitation, engagement strategies, formative feedback and authentic clinical exposure as key areas for improving the effectiveness of the CALP (Table 6). The theme is built based on four subthemes.

Table 6: Response to question on how to make CALP more effective

Themes and subthemes	Codes
Theme: Optimising learning effectiveness through technological, pedagogical, and experiential enhancements	
Sub-theme1: Enhancing learner engagement through visible participation	Mandatory use of video during sessions Visual presence as a driver of engagement Increased accountability and attentiveness Improved peer-to-peer interaction
Sub-theme 2: Addressing technological barriers to effective online learning	Poor internet connectivity Disrupted communication and interaction Reduced participation in online sessions Inequitable access to digital learning resources
Sub-theme 3: Need for formative feedback to support learning improvement	Desire for feedback on individual performance Feedback as a motivator for improvement Guidance for learning progression Support for self-regulated learning
Sub-theme 4: Value of authentic clinical exposure	Examination of real cases in clinical settings Linking theoretical learning with practice Experiential learning within the department Increased clinical confidence and motivation

1. *Enhancing learner engagement through visible participation*

Students highlighted the importance of visible participation in enhancing engagement during online sessions. The mandatory use of video was suggested as a means to improve attentiveness,

accountability, and interaction. Visual presence was perceived to foster a more connected learning environment, facilitating better peer-to-peer communication and active involvement.

2. Addressing technological barriers to effective online learning

Technological constraints emerged as a significant challenge affecting the effectiveness of CALP. Issues such as poor internet connectivity, disrupted communication, and reduced participation were commonly reported. Additionally, inequitable access to digital resources limited the learning experience for some students, indicating the need for improved technological infrastructure and support.

3. Need for formative feedback to support learning improvement

Students expressed a clear need for structured formative feedback on individual performance. Feedback was identified as a key driver for motivation, enabling students to recognise their learning gaps and guiding their progression. It also supported the development of self-regulated learning behaviours.

4. Value of authentic clinical exposure

Students emphasised the importance of integrating authentic clinical experiences into the program. Exposure to real cases within clinical settings was seen as essential for linking theoretical knowledge with practice, enhancing experiential learning, and building clinical confidence and motivation.

Overall, these findings underscore the need for a holistic approach to optimise CALP, integrating technological reliability, active engagement strategies, meaningful feedback, and authentic clinical learning experiences.

Faculty perspective on CALP:

Faculty perspectives highlighted CALP as a contextually responsive and innovative educational approach, with its effectiveness shaped by pedagogical design, learner engagement, and institutional support systems. Five themes were derived from the codes (Table 7).

Table 7: Responses of faculty on perspectives of CALP

Themes	Codes
Theme 1: CALP as a Contextually Relevant Educational Innovation	CALP as a novel teaching experience Contextual relevance of the topic Curriculum gap addressed by CALP Pandemic-driven necessity Online learning as pedagogical rescue
Theme 2: Expanded Access to Clinical Exposure through Digital Modalities	Limited clinical exposure during pandemic Online platforms enabling continuity Technology-mediated access to learning Alternative for in-person clinical learning in crisis situations
Theme 3: Need for Pedagogical Structuring to Enhance Engagement	Large group limitations Small group learning effectiveness Active participation in CBD Facilitated interaction
Theme 4: Promoting Self-Directed Learning and Learner Motivation	Assignments as motivators Self-directed learning Learner accountability Active investment in learning
Theme 5: Importance of Institutional Digital Infrastructure	Need for learning management systems Institutional support for e-learning Digital infrastructure for sustainability Technology-enabled motivation

Theme 1: CALP as a contextually relevant educational innovation

Faculty perceived CALP as a novel and contextually relevant teaching innovation that effectively addressed existing curricular gaps. Its implementation was particularly valued during the pandemic, where it functioned as a pedagogical ‘rescue’, ensuring continuity of learning despite disruptions to traditional teaching. The alignment of CALP with the topic of OPMDs further reinforced its relevance within the curriculum.

Theme 2: Expanded access to clinical exposure through digital modalities

Faculty highlighted that CALP facilitated continued access to clinical learning during periods of limited in-person exposure. Through technology-mediated platforms, students were able to engage with clinical content, making it a viable alternative during crisis situations such as the COVID-19 pandemic. This digital approach helped sustain clinical learning when conventional methods were not feasible

Theme 3: Need for pedagogical structuring to enhance engagement

Faculty emphasised the importance of structured pedagogical approaches to maximise student engagement. While large group sessions are perceived as limiting interaction, smaller group formats and case-based discussions were identified as more effective in promoting active participation, meaningful interaction, and deeper learning.

Theme 4: Promoting self-directed learning and learning motivation

Faculty recognised CALP as a platform that encouraged self-directed learning and learner accountability. Assignments and structured activities were seen as motivating factors that prompted students to actively invest in their learning process, fostering autonomy and sustained engagement.

Theme 5: Importance of institutional digital infrastructure

The effectiveness and sustainability of CALP were closely linked to the availability of robust institutional digital infrastructure. Faculty stressed the need for dedicated learning management systems, institutional support for e-learning, and reliable technological resources to enhance delivery, accessibility, and long-term integration of such programs.

Overall, faculty perspectives underscore CALP as a valuable and adaptive educational innovation, with its effectiveness contingent upon pedagogical structuring, learner engagement strategies, and strong institutional digital support.

Discussion

This study evaluated the effectiveness of CALP among undergraduate BDS students in improving knowledge and understanding of oral potentially malignant disorders. The findings demonstrate a statistically significant improvement in knowledge scores immediately following the intervention, with further improvement observed at three-month follow-up, indicating both the short-term knowledge gains and sustained knowledge retention. In addition, qualitative findings suggest that CALP was positively perceived as an engaging and innovative learning approach that supported clinical reasoning and self-directed learning.

The observed improvement in post-test scores is consistent with previous studies demonstrating the effectiveness of computer-assisted learning in dental education. Wilson et al reported improved post-intervention performance using computer assisted program for radiation protection,¹⁸ while Karemore et al found significant enhancement in students' knowledge and diagnostic skills for white keratotic lesions

following a case based CAL intervention.² These findings support the role of CALP as an effective adjunct to traditional teaching, particularly in clinically oriented subjects requiring visual recognition and diagnostic reasoning. However, studies have also demonstrated contrasting outcomes as reported by Hobson et al that traditional tutorial showed that students taught by the conventional tutorial had a significantly greater knowledge gain compared to CAL.¹⁴ Similarly, Phongthara et al. reported that students in the text-based group resulted in higher test scores than computer assisted instruction (CAI) group. This difference may be explained by factors such as learner familiarity with traditional study methods and potential challenges associated with prolonged screen use, including visual fatigue.¹⁹ These findings highlight the importance of considering blended approaches and underscore the need for future comparative studies incorporating both CAL and conventional teaching modalities.

An important finding in this study was the continued improvement in scores at three-month follow-up. This may reflect reinforcement of learning through subsequent clinical exposure and increased motivation of self-directed learning following the intervention. In contrast, earlier studies by McKeachie and Johnson have reported declining retention rates over time.^{20,21} The sustained improvement observed in this study suggests that case-based, interactive learning may enhance long-term retention by promoting deeper cognitive processing and application of knowledge.

The qualitative findings provide further insight into how CALP influenced learning. Students reported improved ability to correlate clinical presentations with theoretical knowledge and demonstrated greater confidence in identifying and diagnosing OPMDs. The use of authentic clinical images and structured case discussions appeared to facilitate pattern recognition and diagnostic reasoning skills that are often difficult to develop through didactic teaching alone. These findings are consistent with previous research indicating that CAL enhances clinical decision-making and supports applied learning in dentistry. In addition, students described increased motivation for self-directed learning and expressed positive attitudes towards the interactive and flexible nature of CALP. Similar perception has been reported in studies by Karemore et al. and Schitteck et al., where CALP was regarded as an enjoyable and useful educational tool that supported independent learning and everyday clinical decision-making.^{1,2} Other studies have also shown that CAL can enhance learner confidence and encourage active engagement, further reinforcing its value in health professions education.^{18,22-24}

Despite these benefits, participants highlighted limitations related to the lack of direct clinical exposure. Students expressed a desire for opportunities to examine real patients with OPMDs, emphasizing that virtual learning cannot fully replace hands-on clinical experience. This aligns with findings from Hassona et al., who reported that dental students often feel inadequately prepared to diagnose oral lesions and require greater clinical exposure.⁶ These findings suggest that CALP should be viewed as a complementary tool rather than a substitute for clinical training, and that integration with patient-based learning is essential for optimal skill development.

The study also identified several contextual and implementation-related factors influencing the effectiveness of CALP. Reliable access to digital infrastructure, including internet connectivity and

appropriate devices, was highlighted as essential for a smooth learning experience. Previous research has similarly demonstrated that positive attitude towards CAL is associated with digital literacy and access to structured e-learning resources.²⁵ Institutional investments in learning management systems and digital platforms are therefore critical for sustainability and scalability of such interventions.

Pedagogical structuring emerged as another key consideration. Students indicated that smaller group sizes facilitated greater interaction, participation, and depth of discussion, thereby enhancing learning outcomes. Furthermore, the inclusion of feedback was identified as an important component in reinforcing learning. Prior studies have shown that lack of feedback in CAL environments may limit skill acquisition, highlighting the need to incorporate structured feedback mechanisms into program design.²⁶ The thematic analysis further positions CALP as a context-responsive educational innovation. Initially adopted as a pragmatic solution during disruptions to traditional teaching, such as those experienced during the COVID-19 pandemic CALP demonstrates potential for sustained integration into dental curricula. Its effectiveness appears to be driven not only by the use of technology but also by alignment with pedagogical principles, including active learning, case-based reasoning, and learner autonomy.

This study has several limitations. The use of single-group design without a control group limits the ability to directly compare CALP with traditional teaching methods. The relatively small sample size may also reduce generalizability. Additionally, improvements in knowledge scores may have been influenced by concurrent clinical exposure during the study period. Future research should consider larger, multi-center studies with controlled designs to better evaluate the comparative effectiveness of CAL and blended learning approaches.

Conclusion

This study demonstrates that a case-based CALP can significantly enhance knowledge acquisition, retention, and perceived clinical competence in the learning of OPMDs among undergraduate dental students. When integrated with appropriate pedagogical design, feedback mechanisms, and clinical exposure, CALP represents a valuable adjunct to traditional dental education and a promising approach for strengthening diagnostic training in resource-constrained and evolving educational contexts.

Abbreviations

BDS : Bachelor of Dental Surgery

BPKIHS : B.P. Koirala Institute of Health Sciences

CAL : Computer Assisted Learning

CALP : Computer Assisted Learning Program

CBD : Case Based Discussion

CBL : Case based Learning

CODS : College of Dental Surgery

COVID-19 : CoronaVirus Disease of 2019

FGD : Focus Group Discussion

IRC : Institutional Review Committee

MCQ : Multiple Choice Question

OMR : Oral Medicine and Radiology

OPMDs : Oral Potentially Malignant Disorders

SD : Standard Deviation

SPSS : Statistical Package for Social Sciences

Declarations

Ethics approval and consent to participate:

All methods were carried out in accordance with the Declaration of Helsinki.

This was post-graduate thesis research approved by the Institutional Review Committee of B.P. Koirala Institute of Health Sciences, Dharan, Nepal (IRC/2087/020).

Written informed consent from students were obtained.

Consent for publication: not applicable

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Authors' contribution: Kripa Khatiwada was responsible for the concept and design of the work, data collection, draft and revision of manuscript. Jyotsna Rimal, Iccha Kumar Maharjan, Pragya Regmee, Ashish Shrestha and Abhinaya Luitel were responsible for review and supervision. For the qualitative data, Jyotsna Rimal, Sagar Adhikari and Sumana Sulu conducted the initial coding and analysis. Dibya

Khanal, Akunchan Shrestha and Victory Thapa were responsible for editing. All authors critically revised the manuscript and approved the final version.

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