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Original Article

Integration of digital slide-based self-directed learning with the post-class video-recording assignments into oral pathology and diagnosis course can improve dental students' learning outcomes and microscopic diagnosis capability

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KEYWORDS
Digital slide;
Self-directed learning;
Oral pathology;

Abstract *Background/purpose:* Virtual microscopy has long been used in oral pathology laboratory teaching. This study evaluated whether adding post-class video-recording assignments to digital slide-based self-directed learning (SDL) in an undergraduate oral pathology and diagnosis course could enhance dental students' learning outcomes, microscopic interpretation ability, and microscopic diagnosis capability.

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Virtual microscopy;
Learning outcomes;
Post-class video-recording assignments

Materials and methods: Fourth-year dental students enrolled in a one-year oral pathology and diagnosis course at the dental school of National Taiwan University (NTU) were included. The experimental group comprised 32 dental students of the 2024 academic year, while the control group included 41 dental students of the 2023 academic year. Both groups used digital slide-based SDL for the course learning. In addition, the experimental group completed post-class video-recording assignments to assess their impact on the learning performance. Furthermore, we also evaluated whether the post-class video-recording assignments could enhance dental students' microscopic interpretation ability and microscopic diagnosis capability.
Results: Performance on the post-class video-recording assignments showed moderate positive correlations with both microscopic pathology slide test scores and overall course grades (Pearson's $r = 0.44$ and 0.43, respectively). The students who completed the post-class video-recording assignments demonstrated significantly greater improvement in microscopic interpretation ability than those who did not (both *P*-values <0.01).
Conclusion: We conclude that integrating digital slide-based SDL into an oral pathology and diagnosis course improves dental students' learning performance. Furthermore, incorporating post-class video-recording assignments enhances dental students' microscopic interpretation ability and microscopic diagnosis capability.

Introduction

Dentistry is a branch of medicine that focuses on the investigation, diagnosis, and treatment of diseases and conditions of the oral and maxillofacial region. The primary goal of dental education is to develop the competence and skills of the students to become the qualified dentists.[1,2] Oral pathology plays a vital role in developing dental students' skills in this unique and diverse field of dentistry. Thus, oral pathology is a cornerstone of dental education, serving as a bridge between basic biomedical sciences and clinical dental practice. To ensure accurate diagnosis and effective treatment of the oral and maxillofacial diseases, dental students must develop a solid understanding of both the clinical manifestations and histopathological characteristics of a broad spectrum of oral and maxillofacial diseases.[3] This field is primarily responsible for identifying and treating diseases affecting the oral and maxillofacial region and for studying the etiology, process, and effects of these diseases.[1] However, the subject matter is often perceived as abstract and overwhelming, posing significant challenges for the learners.

Traditionally, teaching and learning oral tissues and structures, including oral histology and oral pathology, relies on didactic lectures combined with light microscopy of tissue sections on the glass slides (hereinafter referred to as glass slides).[4,5] This traditional teaching and learning method for oral histopathology, which relies on observation using the light microscopes and glass slides, has many shortcomings. For example, microscopes are expensive to maintain, and stained tissue sections on the glass slides tend to fade. Moreover, the students cannot freely review the glass slides after the class.[5] While effective in many respects, this approach is limited by the fragile glass slides, restricted access to the microscopes, and the inflexible laboratory schedules. These factors hinder the students from repeatedly reviewing the glass slides outside of scheduled sessions and make it difficult for the instructors to highlight the key histological features in real time.

With the advent of digital pathology, the digitized histological sections (hereinafter referred to as digital slides) have emerged as promising alternatives to the glass slides. The digitized histological sections can be stored on the web-based platforms, allowing the students to view, zoom, and annotate cases on the personal computers at any time.[6,7] This flexibility enhances the learning opportunities of oral pathology and aligns with the principles of self-directed learning (SDL). When combined with the structured assignments, the digital slides not only foster deeper understanding but also cultivate the essential SDL skills, such as planning, goal-setting, and problem-solving.

This study compared the difference in dental students' learning outcomes between two groups of fourth-year dental students enrolled in a one-year oral pathology and diagnosis course at the dental school of National Taiwan University (NTU). The experimental group comprised 32 dental students of the 2024 academic year, while the control group included 41 dental students of the 2023 academic year. Both groups used digital slide-based SDL for the course learning. In addition, the experimental group completed post-class video-recording assignments to assess their impact on the learning performance. Furthermore, we also evaluated whether the post-class video-recording assignments could enhance dental students' microscopic interpretation ability and microscopic diagnosis capability.

Materials and methods

Participants

This study included 32 fourth-year dental students enrolled in a one-year oral pathology and diagnosis course in the 2024 academic year at the dental school of NTU as the

experimental group, while 41 fourth-year dental students enrolled in the same oral pathology and diagnosis course in the 2023 academic year were served as the control group for comparison.

Teaching process

We adopted a diversified teaching model. This oral pathology and diagnosis course included lectures, microscopic interpretation, dental chart writing, and small group discussion. The teaching model is a group-based, interdisciplinary, and problem-oriented learning approach. The teachers gave lectures on the fundamentals of oral pathology and diagnosis, while the students practiced microscopic interpretation of tissue sections of oral diseases using the virtual microscopy or so-called the digital slide-based SDL with or without the post-class video-recording assignments. A flipped-classroom strategy was implemented for learning the microscopic pathology. It meant that the dental students were required to record short videos for each digitalized tissue section, explaining observed histological changes in the normal and diseased tissue sections. This approach shifted learning from passive observation to active engagement and reflection. Then, based on the knowledge and skills acquired, the students had a small group discussion on the topics of oral and dental diseases.

Furthermore, this study used the digital slide system of EBM Technologies as its digital slide platform, which provided multiple oral pathology histologic section cases for the students to browse (Fig. 1). The classroom implementation process involved the teachers' introduction of the week's topics and learning objectives during the class, followed by guidance for the students to log into the digital slide platform for the individual observation and learning of digital slides. The teachers explained the key observation points in the digital slides during the class, and then the dental students used the digital slide-based SDL with the post-class video-recording assignments (for the 2024 class) or without the post-class video-recording assignments (for the 2023 class) for learning the oral pathology and diagnosis course after the class. The specific tasks included observing the designated digital slides of various oral and maxillofacial diseases, describing and interpreting the histological changes of tissues after the disease process, increasing the microscopic diagnosis capability through the reading of the digital slides of various oral and maxillofacial diseases, thus enhancing the depth of learning in the oral pathology and diagnosis course for the students.

Study design

The experimental group comprised the 2024 academic year dental students who used the digital slide-based SDL with the post-class video-recording assignments for learning the oral pathology and diagnosis course, which required them to actively describe normal and pathological features of the digital slides (Fig. 2). The control group for comparison consisted of the 2023 academic year dental students who used the same digital slide-based SDL without the post-class video-recording assignments for learning the oral pathology and diagnosis course.

Survey tool

We conducted competency-based assessment, evaluating students based on their performance in the following ways: (1) microscopic pathology slide tests using unseen cases, (2) evaluation of learning outcomes using the digital slide-based SDL with or without the post-class video-recording assignments, (3) lecture examinations, quizzes, and group case discussions, and (4) objective structured clinical examination (OSCE) stations featuring oral pathology scenarios, designed to assess diagnostic reasoning, communication, and professionalism.

In this study, we assessed whether the implementation of post-class video-recording assignments could influence the learning performance. Based on the overall course grades, we analyzed the correlations between the scores of the post-class video-recording assignments and learning performance. The learning performance we evaluated included the microscopic pathology slide test scores and the overall cohort grades of the oral pathology and diagnosis course. Moreover, according to the scores of the

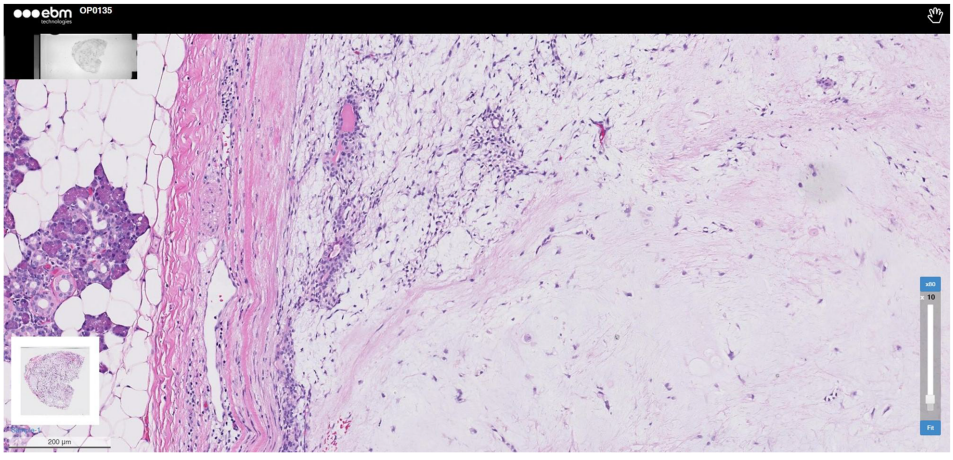

Figure 1 The computer interface of the digital slide system of EBM Technologies in this study.

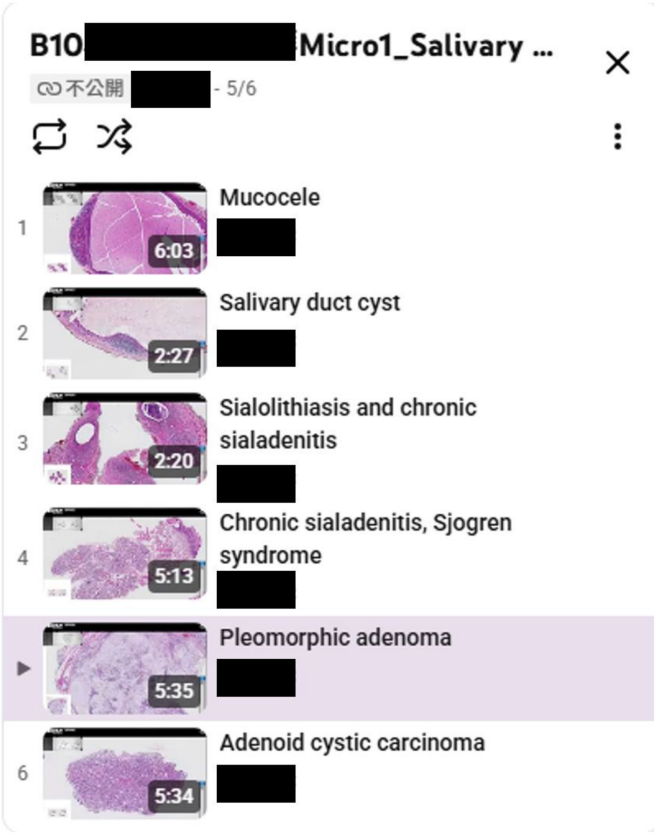

Figure 2 The interface for the students to upload their post-class video-recording assignments using their mobile phones.

microscopic pathology slide tests and the overall semester average grades of the oral pathology and diagnosis course, we calculated the range of improvement in scores or grades from semester 1 to semester 2 to compare the differences in learning performance between the experimental and control groups.

In addition, after the final examination in June 2025, we invited all dental students who took the course of oral pathology and diagnosis to fill out the questionnaires. All dental students were invited to join in this questionnaire survey at their free will to fill out the questionnaires without the pressure from the investigators. This study administered a semi-structured online questionnaire (Google forms) to assess dental students' perceptions of the effectiveness of learning the oral pathology and diagnosis course using the digital slide-based SDL with the post-class video-recording assignments. The questionnaire was designed to ensure participants answered all questions to make sure that the returned electronic survey forms were all complete. These investigated questions included: (1) the ease of use of the digital slide platform, (2) the impact of post-class video-recording assignments on enhancing SDL motivation, and (3) the expectation that this teaching method can continue to be used in the future courses. The questionnaire was designed to allow participants to express agreement or disagreement with each question. At the end of the questionnaire, there was an open question about the participants' learning. The participants could provide any suggestions and/or opinions (including advantages and disadvantages).

Statistical analysis

All data collected were stored in SPSS files and used for statistical analysis. The correlation between the scores of the post-class video-recording assignments and learning performance was analyzed by Pearson correlation. The differences in the mean scores and grades of various investigated items were compared between two groups by independent sample *t*-test. The result was considered to be significant if the *P*-value was less than 0.05.

Ethical consideration

This study was approved by the Research Ethics Committee of NTUH (No. 202407224RINB).

Results

Correlations between the post-class video-recording assignments and the learning performance

The correlation analysis was used to explore the Pearson correlation between the scores of the post-class video-recording assignments and the learning performance. The data trends were then visualized using scatter plots and regression lines (Fig. 3). The post-class video-recording assignment performance demonstrated moderate positive

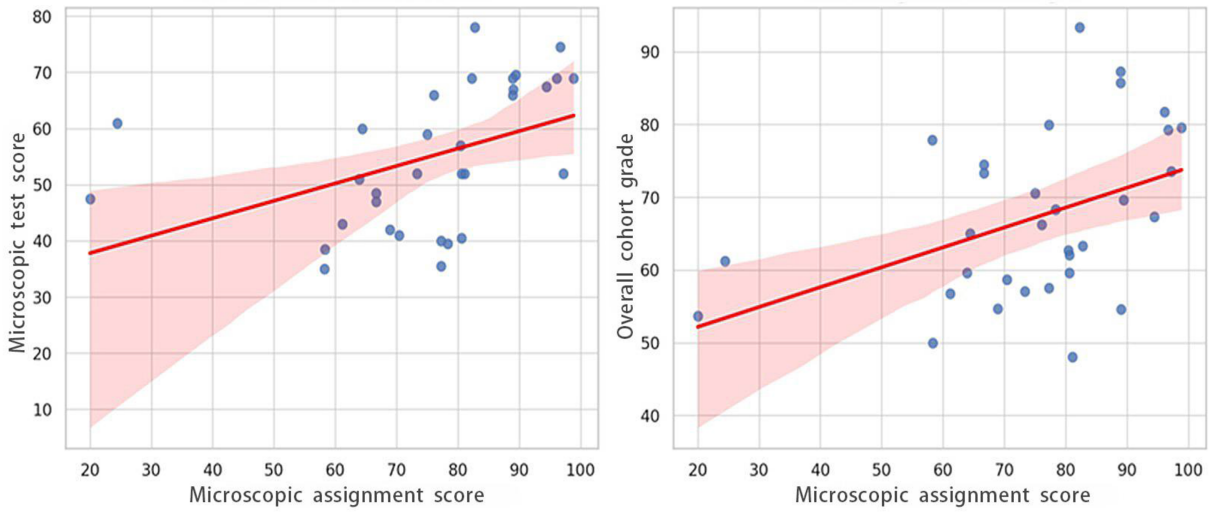

Figure 3 The scatter plots and regression lines of the post-class video-recording assignment scores versus microscopic pathology slide test scores (left) and versus overall cohort grades of the course (right) showed that the post-class video-recording assignment performance demonstrated moderate positive correlations with both the microscopic pathology slide test scores and the overall cohort grades of the course (Pearson's r = 0.44 and 0.43, respectively).

correlations with both the microscopic pathology slide test scores and the overall cohort grades of the oral pathology and diagnosis course (Pearson's r = 0.44 and 0.43, respectively). The students reported that the post-class video-recording assignments supported the review of the course and memory retention, although some perceived the additional workload and stress.

Cohort comparisons in the learning performance between the experimental and control groups

The range of improvement in scores or grades from semester 1 to semester 2 was calculated to compare the differences in the learning performance between the experimental and control groups. The comparisons across semesters showed upward trends in the scores of the microscopic pathology slide tests within the students of the same academic year. In the experimental group (with the post-class video-recording assignments), the students' scores improved from 53.9 to 75.3, representing an improvement of 21.4, while their median scores increased from 57 to 83. Moreover, in the control group (without the post-class video-recording assignments) the students' scores improved from 49.8 to 72.1, representing an improvement of 22.3, while their median scores increased from 52 to 75. Although the students in the control group achieved slightly higher improvement compared to those in the experimental group, this difference in score improvement did not reach the statistical significance ($P > 0.05$) (Table 1).

Furthermore, the comparisons across semesters showed downward trends in the overall semester average grades of the course within the students of the same academic year. In the experimental group, the students' course grades reduced from 75.3 to 72.6, representing a grade reduction of 2.6. Moreover, in the control group, the students' course grades reduced from 82.4 to 76.0, representing a grade reduction of 6.4. Although the students in the experimental group achieved lower course grade reduction compared to those in the control group, this difference in the course

Table 1 Comparisons of the learning performance between the experimental group and control group.

	First semester	Second semester	Improvement
Scores of the microscopic pathology slide tests			
2024 academic year (Experimental group, n = 32)	53.9 ± 14.5	75.3 ± 11.0	21.4 ± 15.8
2023 academic year (Control group, n = 41)	49.8 ± 11.2	72.1 ± 11.8	22.3 ± 14.1
Independent sample *t*-test			$P > 0.05$
Overall semester average grades of the oral pathology and diagnosis course			
2024 academic year (Experimental group, n = 32)	75.3 ± 6.9	72.6 ± 8.2	−2.6 ± 10.5
2023 academic year (Control group, n = 41)	82.4 ± 6.1	76.0 ± 6.9	−6.4 ± 9.4
Independent sample *t*-test			$P > 0.05$

Experimental group: The dental students used the digital slide-based self-directed learning (SDL) with the post-class video-recording assignments for learning the oral pathology and diagnosis course.
Control group: The dental students used the same digital slide-based SDL without the post-class video-recording assignments for learning the oral pathology and diagnosis course.

grade reduction did not reach the statistical significance ($P > 0.05$) (Table 1).

Comparisons of the ratio of the scores of the microscopic pathology slide tests to the overall semester average grades between the experimental and control groups

The ratio of the scores of the microscopic pathology slide tests to the overall semester average grades of the course was calculated to compare the differences in the weight of microscopic interpretation ability within the overall performance. In the comparison of the first semester, the students in the experimental group achieved higher weight of microscopic interpretation ability within the overall performance (0.72) compared to those in the control group (0.61).

Furthermore, in the comparison of the second semester, the students in the experimental group still achieved higher weight of microscopic interpretation ability within the overall performance (1.05) compared to those in the control group (0.94). The students in the experimental group achieved significantly higher acquisition of microscopic interpretation ability compared to those in the control group (both *P*-values <0.01) (Table 2).

Students' perceptions of the effectiveness of learning the oral pathology and diagnosis course using digital slide-based self-directed learning with the post-class video-recording assignments

The results of the learning attitude and satisfaction questionnaire were as follows: (1) 29 (90.6 %) students found the digital slide platform easy to operate; (2) 28 (87.5 %) students agreed that this teaching method of the post-class video-recording assignments enhances their motivation for SDL; (3) 30 (93.8 %) students hoped that this teaching method can continue to be used in the future courses (Table 3).

Furthermore, the common themes in students' qualitative feedback included: (1) It's very helpful to be able to repeatedly observe blurry areas; (2) It eliminates the need to queue for the microscope, making time management easier; (3) The learning guide helps me to understand what to observe, preventing me from feeling lost.

The student feedback indicated that while the students acknowledged the increased workload, they valued the opportunities for flexible review and active engagement. Overall, the students expressed positive attitudes toward the digital slide-based SDL model.

Discussion

From the perspective of applying digital slides to medical education, the results of this study support existing literature highlighting the effectiveness of using digital slides in pathology teaching. Prior research has demonstrated that the digital slides can improve diagnostic accuracy, facilitate interactive learning, and support remote access.[8,9]

The digital slides play a crucial role in pathology teaching and learning. The students using digital slides performed better than the traditional instructors in pathological identification and clinical case analysis. Because digital slides provide high-resolution images and diverse viewing tools, the students can observe from different perspectives, enhancing their ability to identify key histopathological changes in the tissue sections of specific oral

Table 2 Comparisons of the ratio of the scores of the microscopic pathology slide tests to the overall semester average grades of the oral pathology and diagnosis course between the experimental group (n = 32) and control group (n = 41).

	First semester	Second semester
Ratio of the scores of the microscopic pathology slide tests to the overall semester average grades of the oral pathology and diagnosis course		
2024 academic year (Experimental group, n = 32)	0.72 ± 0.19	1.05 ± 0.18
2023 academic year (Control group, n = 41)	0.61 ± 0.15	0.94 ± 0.12
Independent sample *t*-test	$P < 0.01$	$P < 0.01$

Experimental group: The dental students used the digital slide-based self-directed learning (SDL) with the post-class video-recording assignments for learning the oral pathology and diagnosis course.
Control group: The dental students used the same digital slide-based SDL without the post-class video-recording assignments for learning the oral pathology and diagnosis course.

Table 3 Students' perceptions of the effectiveness of learning the oral pathology and diagnosis course using digital slide-based self-directed learning (SDL) with the post-class video-recording assignments in the experimental group (n = 32).

Statements that the students agree with	Number	Proportion
(1) Ease of use of the digital slide platform	29	90.6 %
(2) Impact of post-class video-recording assignments on enhancing self-directed learning (SDL) motivation	28	87.5 %
(3) Expectation that this teaching method can continue to be used in the future courses	30	93.8 %

Experimental group: The dental students used the digital slide-based SDL with the post-class video-recording assignments for learning the oral pathology and diagnosis course.

and maxillofacial diseases. In addition, the digital slides can integrate case descriptions, annotations, animations, and quiz questions, transforming pathology from passive observation into an interactive learning process. Furthermore, with the rise of distance learning, digital slides offer greater flexibility and convenience, allowing the students to learn without being confined to physical spaces.[7]

Our findings add to this evidence by showing that digital slides combined with the post-class video-recording assignments foster measurable learning gains and enhance the students' satisfaction. The post-class video-recording assignment performance demonstrated moderate positive correlations with both the microscopic pathology slide test scores and the overall cohort grades of the oral pathology and diagnosis course (Pearson's $r = 0.44$ and 0.43, respectively). This finding indicates that the students have better performance on the post-class video-recording assignments, as well as better performance on the microscopic pathology slide tests and the overall cohort grades of the course.

In this study, the students without the post-class video-recording assignments achieved higher improvement compared to those with the post-class video-recording assignments. However, this difference did not reach the statistical significance ($P > 0.05$). This means that regardless of whether the post-class video-recording assignments were included, the students' year-long learning approach using the digital slide platform contributed to the improvement in their microscopic interpretation ability. We further calculated the ratio of the scores of the microscopic pathology slide tests to the overall semester average grades of the course to compare the differences in the weight of microscopic interpretation ability within the overall performance. The students with the post-class video-recording assignments achieved higher weight of microscopic interpretation ability within the overall performance compared to those without the post-class video-recording assignments. This means that within the overall performance, the post-class video-recording assignments contribute more to the students' acquisition of microscopic interpretation ability (both P-values <0.01).

From the perspective of SDL in medical education, adult learning theory of SDL provides a framework for fostering autonomy, persistence, and critical reasoning.[10] The digital slides embedded in the structured, task-based learning environments align well with the SDL principles. In the field of medical education, the SDL combined with digital tools helps to develop clinical reasoning and critical thinking skills. Through repeated practice and actively seeking solutions, the students can gain a deeper understanding of pathological mechanisms and apply their knowledge to the clinical cases. Based on these considerations, this study integrated the digital slides and SDL strategies to design a teaching model that meets the learning needs of the dental students, and has implemented it in the classroom. In this study, by encouraging the learners to reflect, analyze, and explain the histopathological features of the digital slides, the post-class video-recording assignments strengthened the students' accountability and engagement.

This study has several limitations. First, the study was conducted at only one institution, resulting in a relatively small sample size, which may limit the general applicability of the findings. Future research with larger sample sizes, covering different dental education institutions and different levels of dental education, will help to validate the findings. Second, the assessment of the learning outcomes was completed by only one oral pathology teacher, which, despite standardization, may still introduce observers' bias. The digital slide platform used in this study was intended for a short-term application. The students may require longer and more repeated training to enhance their microscopic interpretation ability and self-efficacy. Therefore, future research is recommended to explore the impact of a long-term digital slide platform training programs on the skill maintenance and clinical application.

From the perspective of challenges and opportunities in oral pathology education, oral pathology is often perceived as complex, content-heavy, and abstract, while traditional didactic teaching can limit motivation and diagnostic skill development. Oral pathology covers a wide range of topics, including inflammation, tumors, developmental abnormalities, cysts, and other lesions. The students often report that the course is information-intensive, the images are abstract, and it is difficult to grasp the differentiation between different lesions. The traditional teaching method relies heavily on one-way lectures from the teachers and rote memorization by the students, which can easily lead to the lower learning motivation. By contrast, interactive models such as the digital slide-based SDL encourage deeper engagement and higher-order thinking.[11] Our results suggest that such approaches may help to address the longstanding pedagogical challenges in oral pathology education.

In conclusion, this study demonstrated that integrating digital slides with SDL strategies can improve the students' learning outcomes, lesion recognition, and engagement in oral pathology. The students reported generally positive attitudes, supporting the feasibility and scalability of this model. The educators are encouraged to progressively incorporate the digital platforms with structured learning tasks and interactive discussions to enhance the motivation and performance. Future research should expand the sample size, include the inter-institutional collaborations, and evaluate the long-term impacts on the clinical performance. By providing empirical support for the digital slide-based SDL, this study contributes to the digital transformation of medical and dental education and underscores its alignment with contemporary trends in the learner-centered and technology-integrated pedagogy.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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