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The impact of an online gamified virtual tour on cognitive enhancement in dental practice management

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Dental practice management is usually a mandatory course for both undergraduate and postgraduate programs. However, learners and educators may encounter challenges in gaining experiences in real-life dental practice. The concept of a gamified virtual tour could have potential to improve dental practice management skills. A quasi-experimental study was conducted to evaluate the educational impact of a gamified virtual dental clinic (GVDC) on dental practice management skills among dental undergraduates (UG) and postgraduates (PG). All participants were assigned to complete the GVDC. Pre- and post-knowledge assessments were administered to evaluate knowledge acquisition. A self-administered questionnaire was distributed to investigate user perceptions toward the use of GVDC. There were 20 dental undergraduates and 20 orthodontic residents participating in UG and PG groups, respectively. Both groups demonstrated statistically significant increases in their assessment scores after completing the GVDC ($P < 0.001$). Although the pre-knowledge assessment score of the PG group was notably higher than that of the UG group ($P = 0.041$), there was no statistically significant difference in their post-knowledge assessment score ($P = 0.491$). Participants had positive perceptions of GVDC in terms of usefulness, ease of use, and enjoyment, with no statistically significant differences between the two groups ($P > 0.05$). Overall, the GVDC demonstrated positive educational impacts on acquiring knowledge and understanding of dental practice management, with participants expressing favorable perceptions of this immersive learning intervention.

Keywords Dental education, Gamification, Serious game, Simulation, Technology-enhanced learning, Virtual tour

Dental practice management has emerged to become a set of 21st century skills required for new graduates[1]. This set of skills, including financial management, clinic operation, marketing, leadership, and legal compliance, is essential for the new generation of dentists to run their dental practice, especially in a competitive business environment. However, it seems that many dental schools have not adequately prepared their graduates for practice management[2,3]. Although several continuing education courses in general entrepreneurship are currently available, a specific program in a dental business should be developed not only to enhance profits but also to promote patient rights and professional ethics.

Dental practice management courses should be implemented at both undergraduate and postgraduate levels. Dental professionals consider practice management skills essential for their successful dental practices[4,5]. However, there is evidence suggesting that classes in traditional dental school based settings may not be sufficient for students to master their practice management skills[6]. Although learning in real-life settings (i.e., observation in dental clinics and hospitals) is a possible option, there are difficulties and restrictions in relation to patient privacy, constraints from operational hours, limited exposure to diverse practice management cases, and potential ethical concerns specific to the administrative side of dental care. As a result, technology-enhanced learning may offer a more effective and flexible alternative or supplementary approach in training in dental practice management, overcoming some of these challenges.

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Online serious games have demonstrated their effectiveness as learning tools for dental education. They could provide an interactive asynchronous learning situation, where students could learn with self-motivation and engagement in a safe environment[7–9]. Relevant research in dental education suggests that students have the potential to acquire knowledge through their participation in serious games[10–16]. An activity log function embedded in a game system also allows instructors to indirectly observe learning behaviors, and enables them to identify learners who may have difficulties in achieving expected learning outcomes[17]. Therefore, online serious games can be designed for teaching and learning in dental practice management.

Virtual tours have been demonstrated to be an effective replacement for physical field trips in biology, community pharmacy, and cultural tourism education[18–20]. A gamified virtual tour, that can both simulate dental practice settings and enable dental students to improve their dental practice management skills in an interactive learning environment, could be a novel concept in dental education. There is currently no evidence regarding the effectiveness of virtual tour design in a game-based learning format with respect to improving dental practice management skills. Therefore, we developed a gamified virtual dental clinic (GVDC) and conducted research to evaluate its educational impacts on cognitive enhancement in dental practice management among dental undergraduates (UG) and postgraduates (PG), representing novice and experienced users respectively. The following research aims were established:

1. To assess knowledge improvement among participants after completing the GVDC.
2. To compare knowledge improvement between UG and PG users.
3. To explore user perceptions of the GVDC in terms of usefulness, ease of use, and enjoyment.

Materials and methods

An online gamified virtual tour in dental practice management

The GVDC was designed and developed as an interactive asynchronous learning tool with 360-degree technology. Raw images from a dental hospital were captured using a 360-degree Kandao QooCam camera. Subsequently, these raw images underwent processing and rendering using Qoocam Studio software, resulting in the creation of a comprehensive 360-degree environment. The integration of interactive elements within the virtual tour was accomplished through the utilization of Unity in conjunction with the Microsoft Visual C# programming language. The virtual dental clinic is compatible with various web browsers (e.g., as Google Chrome, Safari, and Microsoft Edge), and can be accessed on multiple devices (e.g., laptops, tablets, and smartphones).

Following a registration or log-in process, learners were allowed to navigate and explore a number of functional spaces in the GVDC, e.g., reception desk, waiting area, operation room, and in-patient department. Each area had interactive points where users could click to enable a pop-up window showing specific learning content. In addition, the game concept was implemented into the GVDC to enhance the motivation and engagement of the game. For example, users were required to seek hidden items in each room to unlock an achievement. Upon completing all game tasks, learners were expected to identify key principles of effective dental practice management and apply appropriate safety protocols and infection control procedures in dental practice. The user interface of the virtual dental clinic is presented in Fig. 1.

Research design

This study employed a quasi-experimental design to compare the educational impact of a virtual dental clinic between UG and PG users. All participants from both experimental groups were assigned to complete a pre-knowledge assessment to evaluate their background knowledge. They were tasked to navigate and explore the GVDC for a session of two hours within a controlled environment after a one-week interval to minimize potential knowledge retention. Immediately following the completion, a post-knowledge assessment was administered to evaluate knowledge acquisition resulting from their interaction with the GVDC. A perception questionnaire was administered to assess participants' perceptions of the GVDC, addressing its usefulness, ease of use, and enjoyment. The participants completed all GVDC-related tasks and the perception questionnaire independently, without peer collaboration, to ensure individual learning experiences. Research team members (M.C., Y.K., and K.S.) were present throughout the activity to oversee the learning environment and address technical issues as needed. However, they refrained from providing assistance with learning-related queries to ensure that each participant's experience remained independent and unbiased. The data collection procedures were conducted between May and August 2023.

Research participants

The research participants included fifth-year dental undergraduates and orthodontic residents at the Faculty of Dentistry, Mahidol University for UG and PG groups, respectively. These individuals served as novice and experienced learners. Exclusion criteria for the UG group were individuals with any prior work experience in private dental practice. For the PG group, exclusion criteria applied to those without experience in private dental practice environments or if they owned private dental practices.

The participants were recruited to this research using a volunteer sampling. This non-probability sampling approach technique was considered appropriate for this study although non-response bias is a possible concern[21]. Participants willingly engaged in the learning activity, resulting in accurate and reliable research findings without any dropouts[22].

As the main objective was to evaluate knowledge acquisition after interacting with the GVDC, the sample size was calculated employing a formula designed for the comparison of means in two related samples[23]. To ascertain a significant difference in scores between the pre- and post-knowledge assessments, with a statistical power of 80% and a level of statistical significance set at 1%, 16 participants were required for each group. With

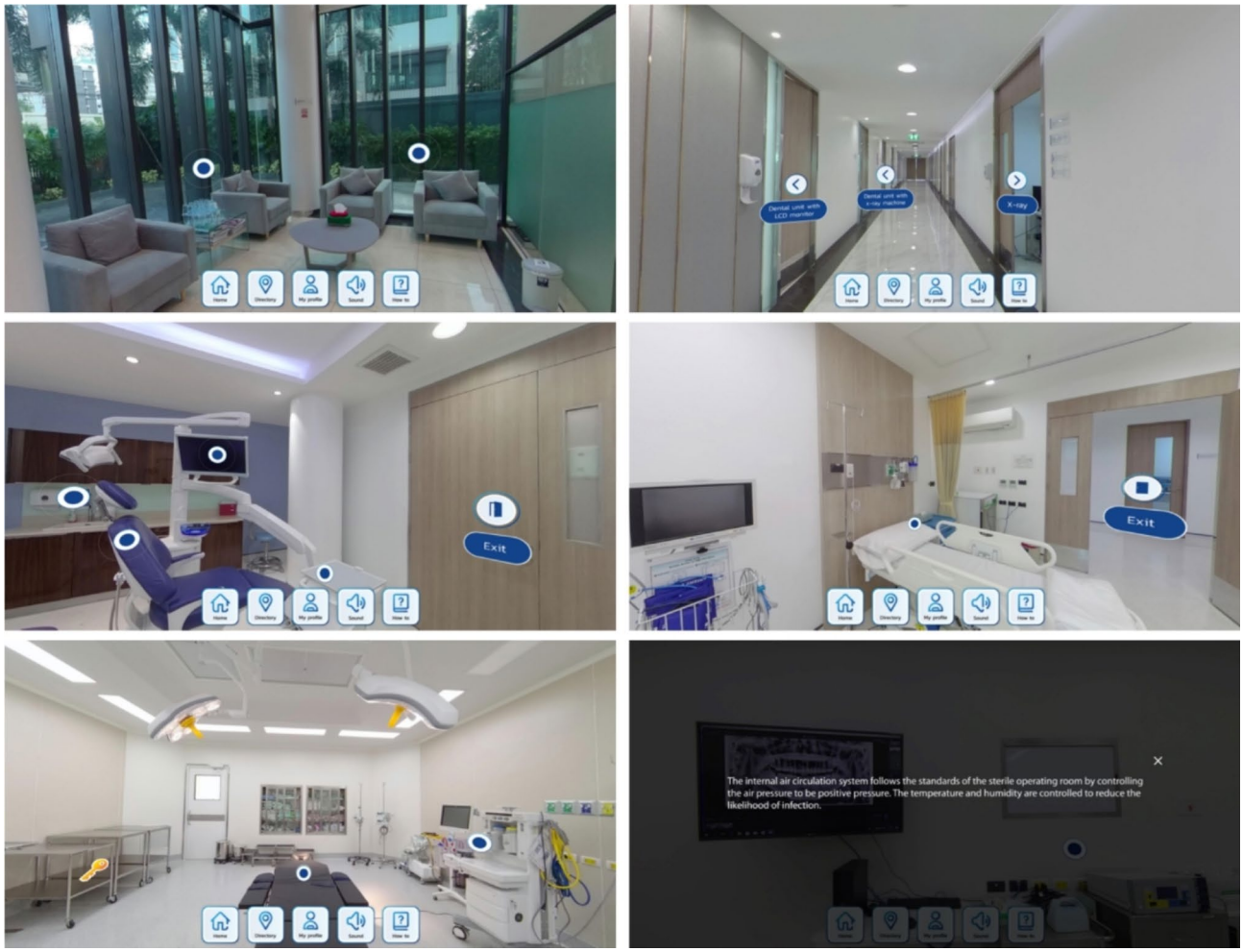

Fig. 1. User interface of the GVDC where learners could interact with the game.

an assumed dropout rate of 20%, the number of participants for each group was set to be 20. Therefore, 20 dental undergraduates and 20 orthodontic postgraduates were included in this research.

Outcome measurements

Knowledge assessments

To evaluate knowledge acquisition, all participants from both UG and PG groups were required to complete the pre- and post-knowledge assessments. The knowledge assessments comprised 15 similar multiple-choice questions yielding a maximum score of 15 points. To mitigate potential test-retest memory effects, the questions and answer choices were subjected to randomization across both assessments[24–26]. The knowledge assessment was constructed by the research team to align with the expected learning outcomes of GVDC. Examples of items from the knowledge assessment and their corresponding learning outcomes are presented in Table 1. To ensure the assessment's quality and relevance, both content and face validity were evaluated before administering the assessment to participants.

Content validity of the knowledge assessment was performed by a panel of three experts, consisting of two specialists in dental education and one with expertise in dental business. None of these experts were directly involved in the study. This process ensured that the assessment adequately covered the expected learning outcomes and was relevant to the field of dental practice management. In addition, face validity was evaluated to ensure that the assessment measured what it was intended to measure in a manner that was understandable and applicable to the participants.

User perceptions

The self-administered questionnaire implemented in this study comprised 15 five-point Likert scale questions, adapted from previous studies[13,24,25]. These questions covered three essential dimensions in evaluating serious games, including usefulness, ease of use, and enjoyment (Table 2). Participants were asked to provide their ratings using the scale, where '1' and '5' indicated 'Strongly disagree' and 'Strongly agree' respectively.

To ensure the robustness and quality of the questionnaire, content validity was rigorously assessed. Three experts in dental education were asked to review the questionnaire. Problematic items were iteratively revised

Questions	Expected learning outcomes
Which of the following is the most accurate description of an effective operating room in a dental clinic? a. The room should be designed to prevent large crowds. b. The room should have a proper air conditioning system to maintain negative air pressure. c. The room should maintain strict control of temperature and humidity to prevent infections. d. The room should include both negative air pressure and strict control of temperature and humidity.	To identify key principles of effective dental practice management
What is the recommended method for sterilizing dental instruments? a. Wiping instruments with disinfectant between patients. b. Using an autoclave to achieve proper sterilization. c. Soaking instruments in a disinfectant solution. d. Rinsing instruments under hot water.	To apply appropriate safety protocols and infection control procedures in dental practice
What should be done with a used needle or sharp object in a dental clinic? a. Place it in a regular trash container. b. Dispose of it in a sharps container specifically designed for such waste. c. Reuse it after cleaning with a disinfectant. d. Flush it down the toilet.	To apply appropriate safety protocols and infection control procedures in dental practice

Table 1. Examples of assessment questions and their associated learning outcomes.

Constructs	Items
Perceived usefulness	- The GVDC helped me better understand dental clinic administration. - The GVDC allowed me to improve my skills in dental clinic administration. - The GVDC reduced travel-related challenges (e.g., time and expenses). - The GVDC shortened my learning time compared to traditional methods (e.g., textbooks). - The GVDC helped me visualize a dental clinic environment more effectively.
Perceived ease of use	- The GVDC was easily accessible with an internet connection. - The GVDC interface was user-friendly and straightforward. - The tour navigation within the GVDC was easy to follow, allowing for thorough exploration. - The images and text in the GVDC were clear and easy to read. - The language used in the GVDC was simple and understandable.
Perceived enjoyment	- The features of the GVDC made learning more engaging. - The challenges in the GVDC motivated me to complete all learning tasks. - Interacting with the GVDC made the learning process more enjoyable. - The simulated experience of visiting a dental clinic enhanced my enjoyment. - The visual design of the GVDC was visually appealing and attractive.

Table 2. Constructs and their corresponding questionnaire items for evaluating the GVDC.

until they reached a satisfactory item-objective congruence index (greater than 0.5). The questionnaire was subsequently piloted with a group of dental undergraduates and postgraduates after the completion of GVDC. Internal consistency was evaluated using Cronbach's alpha coefficients, which were above 0.7 for all constructs, indicating good reliability. No item was removed from the questionnaire based on these results. Additionally, face validity was assessed to ensure that participants perceived the questionnaire items as clear.

Data analysis

The data analysis was conducted using the Statistical Package for Social Sciences software (SPSS, version 29, IBM Corp., Armonk, NY). Descriptive statistics were used to provide an overview of the data. Knowledge acquisition was assessed using a paired t-test. An independent t-test was employed to compare knowledge improvement and user perceptions between the UG and PG groups. The significance level was set at $P < 0.05$.

Ethics statement

This research was approved by the Institutional Review Board of Faculty of Dentistry and Faculty of Pharmacy, Mahidol University on 21st February 2023 (the certificate of approval number: MU-DT/PY-IRB 2023/018.2102). All methods were carried out in accordance with relevant institutional guidelines and regulations. Informed consent was obtained from all participants.

Results

Research participants

The study involved 20 dental undergraduates and 20 orthodontic residents. All the participants completed the learning tasks assigned within the GVDC, the knowledge assessments, and the perception questionnaire, yielding a 100% response rate.

Knowledge improvement

There were statistically significant increases in the assessment scores in both UG and PG groups ($P < 0.001$), as presented in Table 3. The results obtained from UG and PG groups demonstrated a significant improvement in scores from 11.8 (SD = 1.44) to 16.1 (SD = 1.37) and from 12.9 (SD = 1.83) to 16.4 (SD = 1.35), respectively.

Groups	Pre-knowledge assessment Mean (SD)	Post-knowledge assessment Mean (SD)	Mean difference (95% CI)	*P*-value
UG group	11.8 (1.44)	16.1 (1.37)	4.3 (3.77–4.83)	< 0.001
PG group	12.9 (1.83)	16.4 (1.35)	3.5 (2.61–4.39)	< 0.001

Table 3. The scores from the knowledge assessments of both UG and PG groups. The full scores of both knowledge assessments were 20. The significance level was taken at $P < 0.05$.

Assessments	UG group Mean (SD)	PG group Mean (SD)	Mean difference (95% CI)	*P*-value
Pre-knowledge assessment	11.8 (1.44)	12.9 (1.83)	1.1 (0.46–2.15)	0.041
Post- knowledge assessment	16.1 (1.37)	16.4 (1.35)	0.3 (-0.57-1.17)	0.491
Score improvement	4.3 (1.13)	3.5 (1.91)	0.8 (-0.21-1.81)	0.115

Table 4. Comparison of knowledge assessment scores between UG and PG groups. The full scores of both knowledge assessments were 20. The significance level was taken at $P < 0.05$.

Perceptions	UG group Mean (SD)	PG group Mean (SD)
Perceived usefulness	**4.22 (0.55)**	**4.45 (0.48)**
- The GVDC helped me better understand dental clinic administration.	4.15 (0.67)	4.45 (0.51)
- The GVDC allowed me to improve my skills in dental clinic administration.	4.10 (0.85)	4.00 (0.73)
- The GVDC reduced travel-related challenges (e.g., time and expenses).	4.45 (0.83)	4.55 (0.60)
- The GVDC shortened my learning time compared to traditional methods (e.g., textbooks).	3.80 (0.95)	4.50 (0.69)
- The GVDC helped me visualize a dental clinic environment more effectively.	4.60 (0.60)	4.75 (0.55)
Perceived ease of use	**4.15 (0.62)**	**4.32 (0.64)**
- The GVDC was easily accessible with an internet connection.	4.40 (0.68)	4.45 (0.69)
- The GVDC interface was user-friendly and straightforward.	3.75 (0.85)	4.00 (0.86)
- The tour navigation within the GVDC was easy to follow, allowing for thorough exploration.	4.30 (0.86)	4.55 (0.60)
- The images and text in the GVDC were clear and easy to read.	3.95 (0.60)	4.20 (0.90)
- The language used in the GVDC was simple and understandable.	4.35 (0.88)	4.40 (0.68)
Perceived enjoyment	**4.35 (0.64)**	**4.10 (0.51)**
- The features of the GVDC made learning more engaging.	4.55 (0.60)	4.65 (0.59)
- The challenges in the GVDC motivated me to complete all learning tasks.	4.60 (0.60)	4.40 (0.68)
- Interacting with the GVDC made the learning process more enjoyable.	4.20 (0.83)	3.35 (0.88)
- The simulated experience of visiting a dental clinic enhanced my enjoyment.	4.05 (0.83)	3.95 (0.69)
- The visual design of the GVDC was visually appealing and attractive.	4.35 (0.81)	4.15 (0.75)

Table 5. User perceptions in terms of usefulness, enjoyment, and ease of use. Note: User perceptions on a five-point Likert Scale, ranging from 'Strongly disagree' (1) to 'Strongly agree' (5).

Comparison of knowledge improvement between the UG and PG groups

In the comparison of the two groups (Table 4), the pre-knowledge assessment score of the PG group was significantly higher than that of the UG group ($P = 0.041$), while there was no statistically significant difference in the post-knowledge assessment score ($P = 0.491$). However, the score improvements were found to be no significantly different between UG and PG groups ($P = 0.115$).

User perceptions

All research participants in both UG and PG groups completed the perception questionnaire, rating the GVDC positively across usefulness, ease of use, and enjoyment (Table 5). Usefulness was perceived as the most satisfactory aspect, with mean scores of 4.22 (SD = 0.55) and 4.45 (SD = 0.48) out of 5 for UG and PG groups, respectively. Participants particularly valued the GVDC for visualizing a dental clinic environment (UG: Mean = 4.60, SD = 0.60; PG: Mean = 4.75, SD = 0.55) and reducing travel-related challenges (UG: Mean = 4.45, SD = 0.83; PG: Mean = 4.55, SD = 0.60). The UG group rated ease of use lowest (Mean = 4.15, SD = 0.62), with interface user-friendliness being the main concern (Mean = 3.75, SD = 0.85). For the PG group, enjoyment received the lowest score (Mean = 4.10, SD = 0.51), with the learning process enjoyability rated lowest (Mean = 3.35, SD = 0.88). While both groups found the GVDC beneficial overall, their perceptions varied slightly depending on the aspect being considered.

Perceptions	UG group Mean (SD)	PG group Mean (SD)	Mean difference (95% CI)	*P*-value
Perceived usefulness	4.22 (0.55)	4.45 (0.48)	0.23 (-0.10-0.55)	0.164
Perceived ease of use	4.15 (0.62)	4.32 (0.64)	0.17 (-0.23-0.57)	0.396
Perceived enjoyment	4.35 (0.64)	4.10 (0.51)	0.25 (0.12–0.62)	0.180
Overall	4.24 (0.54)	4.29 (0.48)	0.05 (-0.28-0.38)	0.760

Table 6. Comparison of user perceptions between the UG and PG groups. User perception on a five-point Likert Scale, ranging from 'Strongly disagree' (1) to 'Strongly agree' (5). The significance level was taken at $P < 0.05$.

The participants rated the GVDC positively in all aspects without significant differences between both groups ($P > 0.05$), as presented in Table 6. 'Perceived enjoyment' was observed to be most positively perceived in the UG group, receiving a score of 4.35 out of 5 (SD = 0.64). In contrast, the PG group considered this aspect as the least positive, with a score of 4.10 out of 5 (SD = 0.51). However, no statistically significant difference between the UG and PG groups was detected ($P > 0.05$).

Discussion

The GVDC exhibited potential as a technology-enhanced learning tool in a dental practice management course, evidenced by a significant increase in the assessment scores for both UG and PG participants. These assessment scores reflected knowledge improvement, highlighting an important outcome in the evaluation of serious games[7,8,27,28]. Evaluating serious games is essential to ensure they achieve educational goals and provide insights for improving design and effectiveness[12]. In this study, users enhanced their knowledge of dental practice management by interacting with various interactive points within each functional space, which provided explanatory texts on dental practice management within the GVDC.

When considering knowledge improvement between the UG and PG groups, no statistically significant difference in score improvements was observed despite the higher level of knowledge background among the experienced users. This suggests that the GVDC has potential to be an effective tool for beginners, allowing novices to catch up with experienced users. While experience in dental clinics can enhance knowledge and skills in practice management, it is noteworthy that not all aspects of this domain can demonstrate improvement[6]. As a result, a majority of experienced dental practitioners recognize the necessity of effective practice management in their profession[5]. Therefore, both novice and experienced practitioners could benefit from the GVDC.

The design of the game features and challenges in the GVDC was intended not only to enhance entertainment but also to facilitate learner navigation to essential areas within the virtual dental clinic. By incorporating a 'hidden objects' element, users were challenged to search for strategically placed items in key areas of dental practice. This gamified approach, commonly used in virtual tours, ensured that users did not overlook important information[29,30]. The positive perceptions of participants regarding their motivation to complete all game tasks through these challenges reflect the effectiveness of this game element in engaging and motivating users. This evidence supports the role of the gamified elements in enhancing users' sense of accomplishment and motivation to complete the learning tasks.

The participants from both groups found the GVDC to be engaging, as evidenced by their positive perceptions on the enjoyment aspect. The GVDC incorporated various entertaining elements such as a degree of freedom, an achievement system, graphics, and auditory components[12,31–33]. Despite the absence of a significant difference, 'Perceived enjoyment' was most positively acknowledged among the UG users, while the PG group deemed this aspect as the least positive. Considering exploration as a factor enhancing enjoyment within a game context[34,35], this divergence may be attributed to the fact that dental students had no experience outside the dental school setting. Consequently, the exploration of new information in the GVDC could be more exciting for the dental undergraduates compared to the more experienced postgraduate users.

While the robust designs of this research and the data collection tools were intended to minimize potential biases, it is essential to acknowledge some limitations in this study. Notably, only orthodontic residents were included in the PG group for this research. Consequently, future research should consider recruiting postgraduate students from other specialties to ensure its generalization. Additionally, to gain a more comprehensive insight into learning experiences within the GVDC, further research should explore in-depth information and log activity data from users. This approach would contribute to a better understanding of learner experiences, and facilitate the development of the next iteration of the GVDC.

Conclusion

The GVDC exhibited positive educational impacts for users at both undergraduate and postgraduate levels. It facilitated the acquisition of knowledge and understanding of several aspects of dental practice management upon completion of the learning tasks. The participants also expressed positive perceptions of this immersive learning intervention, in terms of usefulness, ease of use, and enjoyment. Future research should explore the effectiveness and development of the game for a wider audience.

Data availability

The data that support the findings of this study are available from the corresponding author, up-on reasonable request. The data are not publicly available due to information that could compromise the privacy of research participants.

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Declarations

Competing interests
The authors declare no competing interests.

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