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Work-in-Progress—Creating Immersive Learning Experiences with Generative AI: a Case Study in Dental Education

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Abstract. In fields such as medical and dental education, Virtual Reality (VR) has shown immense potential for immersive and experiential learning. VR enables realistic virtual patient simulations, providing students with the opportunity to practice a wide range of procedures in a controlled and risk-free virtual setting prior to engaging with actual patients. However, the creation of VR learning experiences poses a significant challenge for many instructors, impeding its widespread adoption and effective use. In this work-in-progress paper, we first report on a study aimed at assessing the difficulties faced by dental instructors in utilising Virtual Reality Haptic Dental Simulators in their teaching. We then present our efforts to develop an AI-aided multimedia content authoring tool tailored for haptic VR dental simulators. This tool is intended to alleviate the need for instructors to possess advanced technical skills, allowing them to focus on their core strengths: subject-matter expertise and instructional design. We describe two approaches: a text-to-3D model generation method enhanced with enriched prompts, and an image-to-3D model generation method, which will soon be capable of incorporating instructional guidelines to generate diverse learning scenarios and use cases.

Keywords: Virtual Reality, Generative AI, Dental Education.

1 Introduction

The field of education is undergoing a profound transformation through the integration of emerging experiential technologies into teaching and learning practices. Among these technologies, Virtual Reality (VR) stands out as particularly promising, gaining substantial traction among both educators and learners. VR holds the potential to revolutionise instructional delivery and enhance learning outcomes by enhancing motivation, engagement, retention, and comprehension through immersive, interactive, and experiential learning environments [8]. A key aspect of VR's effectiveness lies in its ability to immerse learners in computer-generated environments that simulate reality, enabling interaction with virtual objects through devices such as goggles, headsets, gloves, or body suits [12]. Research indicates that VR's capacity to induce a sense of presence in virtual worlds has a comparable impact on learning outcomes to hands-on learning experiences [13,14]. Furthermore, the integration of VR with sensing technologies like haptics has been shown to enhance immersion by providing physical feedback during interactions within the virtual environment [4].

In fields such as medical and dental education, VR facilitates realistic virtual patient simulations, allowing students to practice a wide range of procedures, from routine cleanings to complex surgeries, in a controlled and risk-free virtual environment [5,17]. This immersive experience not only helps students hone their skills but also build confidence, preparing them for real-world scenarios [14] before they encounter actual patients. Recognising the limitations of traditional dental education methods such as cost, risk to live patients and real-time assessment [8], Virtual Reality Haptic Dental Simulators (VRHDS) have been developed to enable dental students to practice various dental procedures on virtual patients without posing any risk to live patients (see Fig. 1) [15]. These haptic simulators, primarily developed by Simodont, SimtoCare and VirtEasy, provide realistic touch sensations, allowing students to perform dental procedures on a virtual model and develop cognitive and psychomotor skills while receiving authentic, detailed feedback that closely mimics real patient experiences [11].

However, as noted by Abeywardena [1], barriers such as the scarcity of open content, tools, and expertise, along with the absence of effective pedagogy and VR instructional design principles, as well as issues related to scalability and sustainability, impede the wider adoption of VR in education. Educators transitioning from instructional design to authoring VR learning experiences play a crucial role in shaping the effectiveness and impact of immersive learning. It involves translating instructional design principles into tangible VR content, which may entail adapting existing materials or creating new immersive resources, 3D models, simulations, and interactive content that are aligned with instructional goals, necessitating a thorough understanding of VR technologies, including their capabilities and limitations.

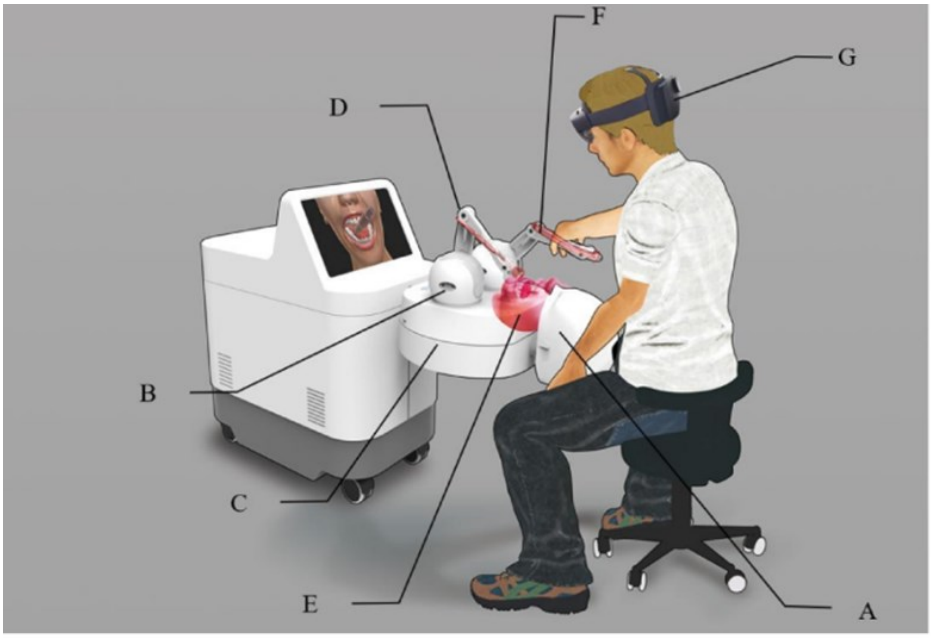

Fig. 1. Schematic diagram of the Unidental Mixed Reality Simulator with (A) a phantom head, (B) haptic device base, (C) haptic device motion platform, (D) haptic device handles, (E) virtual oral environment, (F) virtual dental instruments, and (G) mixed reality eyeglasses [11].

The integration of VRHDS in practical dental training has introduced new challenges, with a significant one being the complexity of developing content for haptic devices, often requiring skills not readily possessed by dental clinical instructors. Consequently, many of these simulators lack sufficient training content covering the range of dental clinical cases necessary for adequately preparing students [11,16]. This issue of instructors facing difficulty in creating VR content is critical because dental clinical instructors not only impart knowledge and skills to dental students but also possess a wealth of academic resources and years of teaching and clinical experience. They have traditionally been responsible for designing and delivering dental education curricula that successfully enable students to acquire clinical competence. Indeed, research on dental skill acquisition using Haptic VR systems indicates that novice trainees achieve optimal acquisition and retention of basic dental motor skills through a combination of instructor guidance and visual display (VR)-driven feedback [2].

Our work aims to explore the feasibility of developing an AI-aided, multimedia content authoring tool tailored for haptic VR dental simulators to alleviate the need for instructors to possess advanced technical skills. Specifically, our objectives are to:

- Assess the feasibility of developing an AI-aided Multimedia Content Authoring Tool for VR Content Authoring.
- Explore and then adapt generative deep learning algorithms that can take text and 2D images of a patient case as input and create pedagogically sound virtual 3D models of teeth and patient scenarios as output for a haptic virtual reality dental simulator.
- Explore the perceptions of dental clinical instructors on the use of AI-aided multimedia content authoring tools for haptic VR dental simulators.

In the remainder of the paper, we first report on a study aimed at assessing the difficulties faced by dental instructors in utilising VRHDS in their teaching. We then present our efforts to develop an AI-aided multimedia content authoring tool tailored for haptic VR dental simulators.

2 Challenges of VR Content Authoring for Dental Instructors

We conducted a study employing a mixed-methods approach (online survey and interviews) to explore the challenges encountered by dental educators in using VRHDS for educational purposes. Ethical approval was obtained, and informed consent was secured from all participants. Data collection took place online between September and December 2023.

2.1 Survey Participants

The survey targeted seven dental faculties in UK higher institutions equipped with VR-haptic simulators represented by dental educators across different roles. Respondents included four dental educators (clinical lecturers), two professors, and one VR-Haptic lab technologists/e-learning managers, with an average of seven years of experience. Age distribution was evenly spread across groups: 26-35 (28%), 36-45 (28%), 46-55 (28%), and above 55 (14%). Educational backgrounds comprised PhDs (42%), Master's degrees (28%), and Bachelor's degrees (28%).

2.2 Interviews

To gain deeper insights, four semi-structured interviews were conducted with participants from Queen Mary University of London, King's College London, University of Newcastle, and Queen's University Belfast/NIMDTA. The participants, selected for their diverse expertise in VRHDS and dental education, included two clinical lecturers and two e-learning resource managers/technologists. Thematic analysis was employed.

The combination of survey (see Appendix A) and interview (see Appendix B) data allows for triangulation of our findings. By comparing the quantitative and qualitative results, we can validate the survey findings with detailed explanations and specific examples obtained through the interviews.

2.3 Results

The survey results (see Fig.2) show that 71.4% of respondents had used haptic VR in their curriculum, and 42.8% had created multimedia content for haptic VR experiences. Below are quotes from the interviews conducted to gain deeper insights into the challenges of dental educators.

"One challenging area of my work involves creating models for cases or scenarios to test student skills in an exam setting."

"When I need to create my own images/models but lack the necessary resources, I resort to a specific workaround. I use photo editing software or other tools to meticulously modify existing images until they accurately represent the scenario I have in mind."

"I'm very interested in the potential of AI-powered solutions that could directly generate high-quality content. However, it's crucial that any such solution meets the high standards of quality and refinement that are essential for effective educational materials."

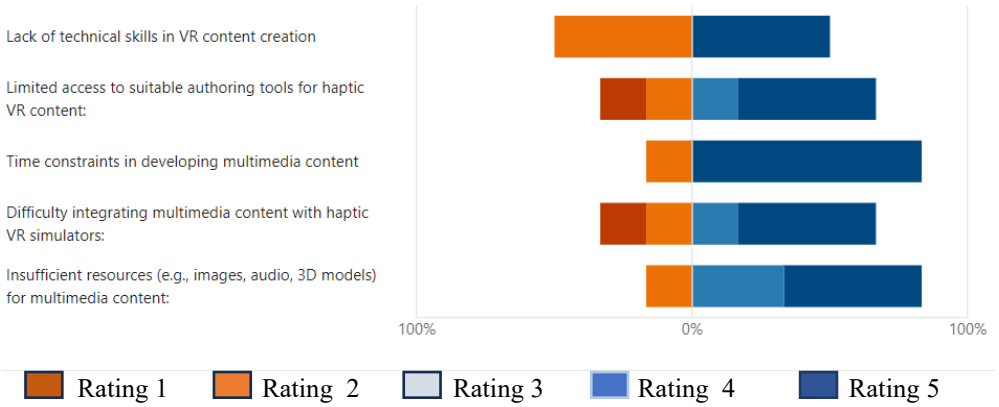

Fig. 2. Survey results for questions on challenges encountered when creating content for VRHDS (Rating 1 being not challenging, Rating 5 being highly challenging).

2.4 Discussion

Dental educators face significant challenges in creating effective VR content, primarily due to the excessive time it takes to design, model, and animate 3D models for specific dental cases. The time commitment required for content creation, competes with dental educators demanding teaching responsibilities. While VR-haptic machines offer pre-installed content, its limited scope often necessitates educators to develop their own customised scenarios. However, the complexity of XR authoring tools poses a significant barrier. These tools often demand specialized technical knowledge and substantial computing resources that many educators lack. This results in the creation of generic or sub-optimal learning experiences, potentially hindering student outcomes.

The issue of "tool siloing," where educators must learn multiple tools for different aspects of content creation, exacerbates these difficulties by increasing the learning curve and impeding seamless integration of components into a cohesive learning experience. Proprietary systems associated with specific VR-haptic simulators further complicate the authoring process, highlighting the need for more accessible and integrated solutions like an AI-aided multimedia content authoring tool tailored for haptic VR dental simulators.

3 Creation of XR Learning Experiences with Generative AI

AI tools, encompassing capabilities like text-to-3D [18] and image-to-3D generation present an opportunity to overcome the complexity barriers associated with traditional XR authoring [6,9]. This innovative approach would allow dental educators to harness the power of AI. By utilising intuitive interfaces and familiar human computer interaction methods like text and speech, the goal is to enable a collaboration with the AI to produce high-quality educational VR content. In this partnership, the dental educator should retain complete ownership and control of the pedagogical content (agency control), while the AI utilises its vast capabilities to assist in the creation process. This collaborative approach, coined" AI-Aided Design and Co-Creation," represents a burgeoning field within the broader realm of human-computer interaction.

Our research explores the potential of AI-Aided Design and Co-Creation in dental education. This approach has already proven successful in other industries, demonstrating its versatility in sectors like automotive and aerospace design [3]. By embracing this innovative collaboration, we aim to empower dental educators and educators generally to create personalised and efficient VR learning experiences for dental students, ultimately enhancing the educational landscape.

3.1 From Text to 3D Models

Existing text-to-3D models like Shap-E and Stable-Zero123 struggle with generating complex medical structures due to their lack of domain-specific knowledge. To address this, we propose a two-step approach: 1) "prompt engineering" to enrich the initial description with relevant details and 2) "diffusion-based 3D model generation" to iteratively refine a random noise image into an anatomically accurate model guided by the enriched prompt. This method aims to improve the performance of AI models in generating 3D models for fields like dental education (see Fig. 3 and 4) [8,7].

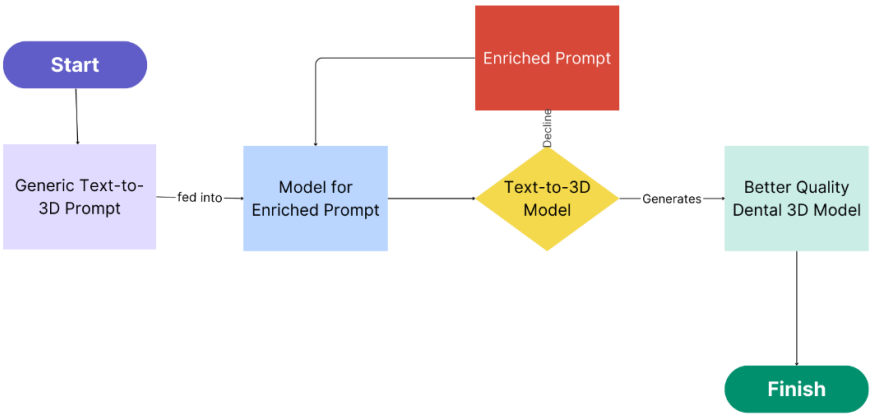

Fig. 3. Prompt Engineering Workflow for Text-to-3D Dental 3D Model Generation.

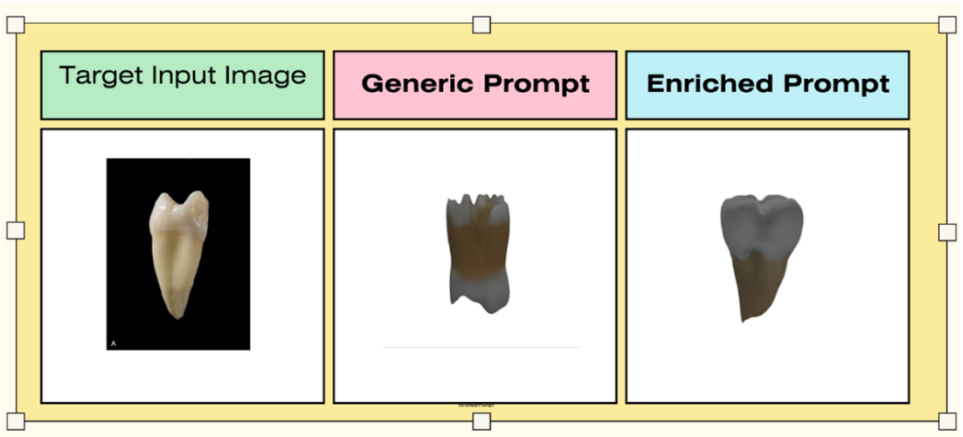

Fig. 4. 3D model generation using generic versus enriched prompt and Text-to-3D model generation.

Examples of prompts and enriched prompts:

- **Prompt:** *you are a dental 3D model prompt generator/ describe a first pre-molar human tooth in 3 sentences for 3D model generation / This prompt will be used for a text-to-3D model for generation/*
- **Enriched Prompt:** *Generate a 3D model of a first human premolar with a single conical root. The crown should be a cylinder with a rounded top, with a diameter of 10mm at the base and 8mm at the top, and a height of 8mm. Add two cusps on the chewing surface: a larger, rounder buccal cusp on the cheek side and a smaller, sharper lingual cusp on the tongue side.*

3.2 From Image to 3D Models

Many educators already possess extensive image libraries containing teeth, oral structures, and even complete dental cases for teaching purposes. Given that images provide clearer instructions for 3D generative models to construct accurate 3D representations, this readily available resource presents an opportunity for co-creation, bridging the gap between educators' subject-matter expertise and the technical demands of 3D model development.

In our research, we compared the effectiveness of image-based prompts versus text-based prompts for generating 3D models using the 3D Gaussian Splatting technique [19]. We found that images provided significantly better instructions for the generative models, resulting in more realistic and accurate 3D representations compared to text-based prompts, even while using an enriched prompt approach (see Fig. 5). This finding aligns with research by [10], who highlights the superior ability of images to convey complex structural details.

By inputting dental images from various angles and modalities, such as intraoral scans and CT data, into the model, the generative model can deduce intricate shape information and generate high-fidelity 3D tooth models. This capability enables educators, even those lacking 3D modeling expertise, to utilise existing image resources and collaboratively create essential 3D models for their VR-haptic learning environments. Ultimately, this enhances the educational experience for dental students.

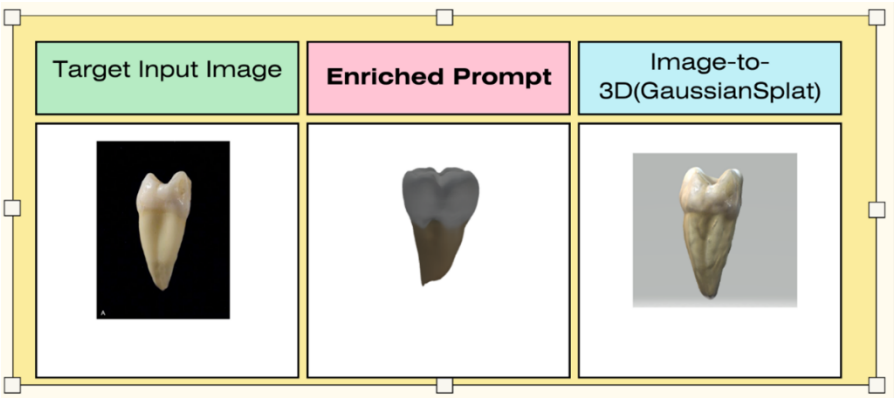

Fig. 5. Comparing results for dental 3D model generation using enriched prompt and image-to-3D model generation using 3D GaussianSplatting

3.3 From Instructional Designs to XR Learning Experiences

Combining AI with instructional design allows for training systems on data and guidelines to create exceptional XR learning materials (see Fig. 6). This empowers educators to participate in the design process, ensuring XR experiences cater to all students. The goal is for features like automatic subtitles, adjustable settings, and alternate content formats to be seamlessly integrated. This keeps educators at the forefront of content development, with AI acting as a supportive tool.

In dental education, AI offers exciting potential for creating rich 3D learning objects for XR experiences. Educators can utilize existing image libraries, transforming 2D pictures of teeth into fully interactive 3D models. This eliminates the need for extensive 3D modeling expertise, allowing them to focus on their core strengths: subject-matter expertise and clear communication.

Furthermore, educators can effortlessly enhance these 3D models with instructional text overlays, which can be converted to audio using text-to-speech systems or even, more engagingly, by utilizing AI to replicate the educator's voice. Research suggests that narrative explanations are more effective for learning than text alone. Imagine students learning from a 3D representation of a complex dental procedure, guided by the familiar voice of their instructor. This personalized and interactive approach has the potential to significantly enhance learning outcomes and student engagement within XR environments. This vision of AI-powered 3D learning objects aligns with the broader aim of utilizing AI as a supportive tool for educators, allowing them to craft truly impactful learning experiences while remaining at the helm of content development.

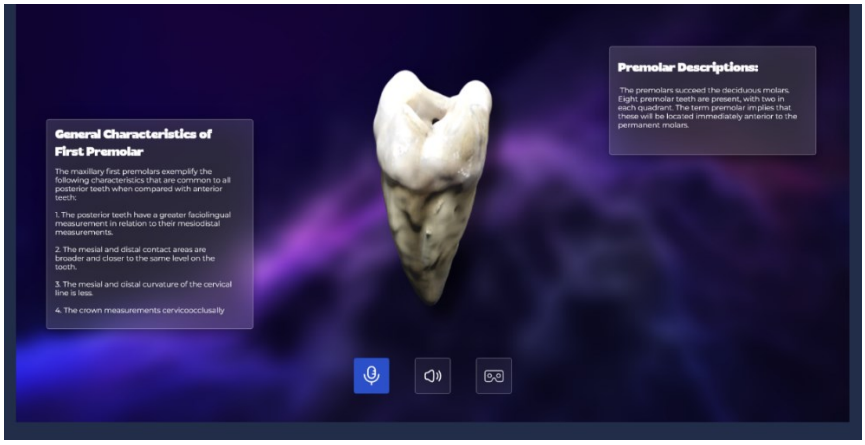

Fig. 6. Generated dental 3D model with overlay text that can be narrated as audio for student learning in XR.

4 Discussion and Conclusion

In the evolving immersive learning landscape, this work proposes an AI-aided framework for dental educators to streamline VR content creation. By leveraging AI tools for automated 3D modeling from text and image inputs, instructors can focus on high-level instructional design while ensuring pedagogical expertise drives the learning experience. However, achieving the right balance where technology complements but does not replace human educators is crucial.

Instructors must retain oversight and control throughout the AI-aided workflow to uphold their pedagogical ownership - the understanding and command over content, delivery methods, and underlying teaching principles. Failure to address this risks a disconnect between the educator's original vision and the final VR output. The proposed solution empowers instructors to review, modify or reject AI-generated models, ensuring personalised and effective learning environments aligned with their goals.

A key limitation of this study is the lack of a comprehensive evaluation framework for the AI-generated models. While initial work with one faculty has begun, defining robust parameters across anatomy, pedagogy, and fidelity through expert reviews, ground truth comparisons, and user studies remains crucial future work. Rigorous quality assessment involving all stakeholders is essential before widespread deployment. Efforts will prioritise developing solutions that reinforce instructors' pedagogical ownership while refining AI capabilities education.

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Appendix

A Sample of Survey Questions

1. Have you used haptic virtual reality (VR) in your dental education curriculum?
2. Have you created multimedia content specifically designed for haptic VR experiences?
3. If you answered "Yes" to the question above, please briefly describe how you have integrated haptic VR into your curriculum and any challenges you have encountered.

B Semi-Structured Interview Questions

1. Following up on your survey responses, we are interested in understanding your experience with creating multimedia content for haptic VR in greater detail.
2. Can you tell us about a specific instance where you encountered challenges in this process?
3. Please describe the nature of the challenge, the steps you took to overcome it, and the outcome of those efforts.
4. What tools do you currently use, if any, to aid your VR content creation? What is good or great about using these tools, and what is terrible?