REFLECTIONS ON PRACTICE

BUILDING CONFIDENCE & COMPETENCY IN THE DELIVERY OF LOCAL REGIONAL ANAESTHESIA BY UNDERGRADUATE DENTAL STUDENTS WITH 3D PRINTED ANATOMIC MODELS & AUGMENTED REALITY TECHNOLOGY

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ABSTRACT

The technology-enhanced learning of a key operative skill in Dentistry was made possible with the development of a realistic three dimensional (3D) printed anatomic simulator. Prior to this development, students at the Faculty of Dentistry, National University of Singapore (NUS) practised the delivery of the inferior alveolar nerve local anaesthetic (IAN LA) injection on classmates after receiving instructions on how to do so from lectures and instructor-led demonstrations. There was no intermediary practice platform. Supported by the NUS Learning Innovation Fund–Technology (LIF-T) grant to address this training gap, the simulator was designed to provide immediate feedback to students on the accuracy of their initial attempts at administering the IAN LA. Augmented reality technology was added to the 3D printed simulator to enhance students' visualisation for placement of the injection needle; it gives an additional feedback perspective to improve procedural accuracy. A usability study was conducted and the feedback collected was analysed. The feedback indicated that students found the 3D printed simulator useful in building confidence and also enabled them to better visualise the IAN LA procedure.

Keywords: Technology-enhanced learning, simulation, 3D printing, augmented reality, feedback

INTRODUCTION

The common challenge faced by dental and medical students is the difficulty in translating and applying anatomical knowledge learnt to the clinical context, particularly in the performance of operative and surgical procedures. With the cessation of the availability of human cadavers, the teaching of human anatomy has moved away from dissection of human cadavers to the use of prosections and plastinated human specimens to help students develop spatial cognition of anatomical structures and layers. Technology, in the form of advanced computer graphics and visualisation modalities, has added richness and realism to images that represent the human anatomy. Contemporary online anatomy teaching resources such as *Cyber-Anatomy Med*, *Acland's Video Atlas of Human Anatomy*, *Zygote 3D Anatomy Atlas & Dissection Lab*, and the *Anatomage Table*, a virtual dissection table, are representative educational resources that use advanced technologies to enhance the learning of human anatomy. However, while these are excellent resources, they lack an important pedagogical component which is the capability to connect the anatomical perspective with the clinical context as seen through the eyes of a clinician. In clinical settings, it is important for dental and medical practitioners to have the ability to see, touch and palpate a structure, and then correlate that information with anatomical knowledge of underlying unseen structures.

In equipping students (novices) with the relevant skills to perform operative procedures on patients, the technology that is adopted must be appropriate and realistic. In using any form of technology to enhance the learning of operative skills, the teacher has to consider the role and reason for using such technology and examine whether the intended learning outcomes were met. In this paper, the authors discuss a framework, developed by the Faculty of Dentistry at the National University of Singapore (NUS), for technology-enhanced learning (TEL). The framework guides the development, use, and evaluation of technology in teaching and learning. This paper will also outline the collaborative journey undertaken by colleagues from the Faculty of Dentistry, the Department of Anatomy at the Yong Loo Lin School of Medicine (YLLSOM) and Keio-NUS CUTE (Connective Ubiquitous Technology for Embodiments) Center in using 3D printing and augmented reality to develop a simulator to build the confidence and capability of undergraduate dental students in performing dental local anaesthesia.

FRAMEWORK FOR TECHNOLOGY-ENHANCED LEARNING (TEL)

The goal of technology-enhanced learning (henceforth TEL) is learning, and technology is the platform to reach this goal. Learning is enhanced when technology increases and improves the quality and value of learning. Technology which engages and enables students throughout their learning journey and enriches their learning experience is more likely to enhance learning. Technology permits the teacher to expand and extend the reach of content beyond the confines of the traditional brick-and-mortar classroom; it also redefines what a classroom is. In adopting a fresh perspective of classroom teaching and learning, technology creates opportunities for learning on demand. Students, across a spectrum of abilities, may learn anytime and anywhere, with or without a teacher.

This framework consists of six principal stages; it simplifies the important sequential steps needed to guide the development, use, and evaluation of technology in teaching and learning.

1. **Reflect on teaching practice**. This is an essential precondition and an important first step. An important question is asked here, "What is the teacher's conception of teaching?" (Kirkwood & Price, 2013). How technology is to be deployed relates to whether the teacher's focus of teaching is on *transmission* of knowledge or on *learning*. If it is the former, a teacher is likely to use technology which transmits information, while the latter will leverage technology to generate and cultivate learning. This is an important step to help teachers reflect on how they view teaching before taking the next step.

2. **Identify the learning gap**. This is an important second step where the teacher identifies the learning gap between expected and actual learning outcomes, and assesses if the gap may be bridged by either a technology-based solution or some other form of intervention.

3. **Design, develop, and implement technology solution**. In designing and developing a technology-enabled learning intervention, the approaches taken to address the educational need/gap must be aligned with educational goals, which are the learning outcomes in a course of instruction. If the intended learning outcome is for students to perform a procedure accurately, the technology must be designed and developed such that it would elicit the expected standard of skills and knowledge from the learner. Guidelines for the development of a TEL intervention are found in instructional design

approaches such as the ADDIE framework by Morrison, Ross, Kemp, and Kalman (2007), Gagné's nine events of instructions for instructional design (Gagné, Briggs, & Wager, 1992), and Richard Mayer's 12 principles for multimedia instruction (Mayer, 2008). Relevant educational theories ought also be considered to inform the design, development, and purchase of the technology solution. It is important for educators to be adequately prepared before they implement the TEL intervention or solution in a course or module.

4. **Assess learner satisfaction (usability)** through peer review and by testing usability. The extent to which students and faculty find the technology prototypes and finished product usable are important factors which can determine the uptake and success of the TEL solution. Educator should seek student and faculty feedback during the trial usage phase, and these comments can be incorporated during the process of refining the product in order to achieve the desired educational goals. The usability of a TEL solution may be evaluated by applying Jakob Nielsen's "five quality components of usability—learnability, efficiency, memorability, errors, and satisfaction" (Nielsen, 2012).

5. **Assess learner gain (outcomes).** Educators may evaluate the learner gains which can be derived from the TEL solution in various ways—through a peer preview process, administering pre- and post-test questions among learners and applying appropriate experimental designs, using QUESTS principles (Harden, Grant, Buckley, & Hart, 1999) based on Best Evidence Medical Education (BEME) guidelines (Issenberg, McGaghie, Petrusa, Gordon, & Scalese, 2005), and applying Levels 2, 3, and 4 of Kirkpatrick's (1996) four-level model of evaluation. Educators can also consider doing a cost-benefit analysis of the TEL solution at this juncture, as well as evaluate the cost of reusability and sustainability of the solution.

6. **Assess learner impact (behaviours).** The final and sixth section asks important questions under a research framework to study the potential impact of TEL on students' behaviours/actions within the context of the curriculum. Educators can discern the value of developing and using the TEL solution based on the extent to which it has led to improvements in students' practice. For example, empirical research can be carried out to determine the extent the TEL solution has resulted in higher levels of efficiency in terms of students' performance of a time-sensitive clinical procedure which is commonly carried out within the curriculum.

DEVELOPMENT OF THE SIMULATOR FOR THE INFERIOR ALVEOLAR NERVE LOCAL ANAESTHESIA

The journey undertaken by the team in developing this simulator to its current version mirrors the first five stages of the framework for TEL mentioned above. The team is currently assessing students' learning gains (Stage 5) under a programmatic project funded by a Singapore Ministry of Education Tertiary Education Research Fund (MOE-TRF).

Reflection on practice and identification of learning gap

The ability of a dentist to perform any invasive procedures on the lower teeth and lower jaw (the mandible) without causing the patient any pain or anxiety is largely dependent on the effectiveness of the local anaesthesia. The inferior alveolar nerve (IAN) is the target nerve for anaesthesia; located 2-3cm under the mucosa on the lingual side of the mandible. The injection needle must be oriented correctly while penetrating through the mucosal surface lateral to the pterygo-mandibular raphe and deeper structures, such as the medial pterygoid muscle, until the tip of the needle reaches the lingula of the mandible. The risk of unwanted tissue damage is high if the injection needle is incorrectly oriented. Administering a IAN nerve block is essentially a procedure which the dentist has to carry out blinded to the internal deep structures.

Dental students learn very early in their undergraduate training to deliver the inferior alveolar nerve regional local anaesthetic (IAN LA) block. Prior to 2017, dental students would learn to administer the IAN LA block through lectures, followed by watching demonstrations by the instructors. Students then proceed to practise the procedure on their classmates before attempting an actual injection on their first patients. For a novice dental student, the prospect of holding an injection syringe with a 4cm needle, and placing that needle into a complex anatomic space with important structures that could be damaged, can be nerve wrecking (no pun intended). There is no intermediary practice platform for students to practice before they administer the injection on their classmates!

To address this considerable training and learning gap, the team developed a multimedia resource and a simulator for IAN LA training (Figure 1), which was supported by an NUS Learning Innovation Fund–Technology (LIF-T) grant. Completed in 2016, the first batch of Year 2 undergraduate dental students used the simulator in April 2017 as an intermediary training and familiarisation practice platform prior to delivering the injections on classmates. Since then, three batches of Year 2 dental students have used the IAN LA simulator.

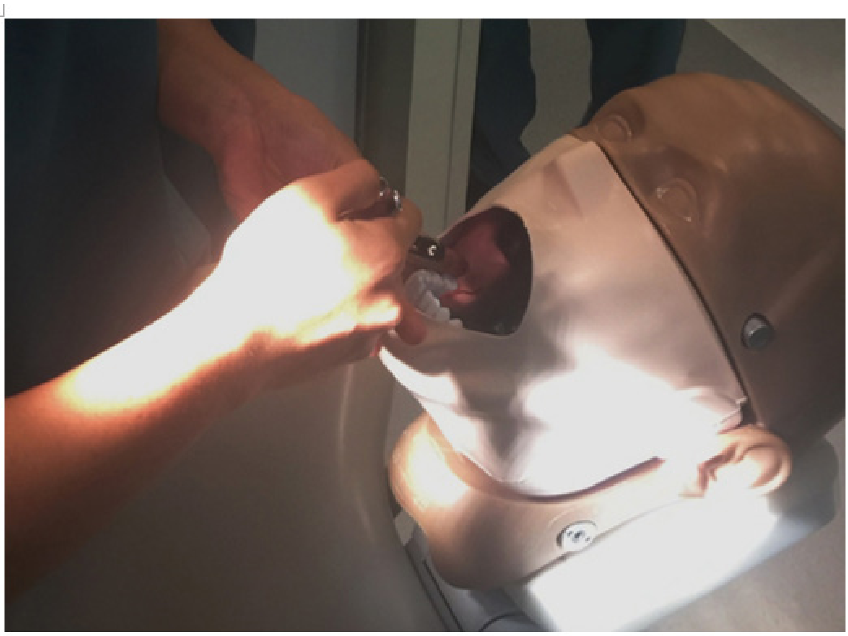

Figure 1. An undergraduate dental student gives a local anaesthetic injection on the 3D printed simulator mounted on a phantom head attached to a dental chair.

CONSTRUCTION OF THE IAN LA SIMULATOR

A 3D printed model of a lower jaw and teeth were created from the lead author's CT scan. The soft tissue on the 3D printed model, representing the pterygo-mandibular raphe, was made from opaque silicone which was cast from a mould. The mould was previously formed by sculpting dental wax to replicate the anatomic shape and size of the lead author's soft tissue intra-oral structures.

Giving students immediate feedback on the accuracy of their attempted injection procedures was an important pedagogical consideration when designing the simulator. The design team from the Keio-NUS CUTE Center incorporated conductive material around the lingual region which approximates the location of the IAN; they also built a simple electrical circuit which connects to a small light bulb and a 3V watch battery. When the tip of the injection needle makes a contact within the target area lined with conductive materials, the bulb would light up to indicate that the student made a "successful" injection attempt on the simulator. The light bulb incorporated into the simulator meant students received immediate feedback on the accuracy of their technique. If the bulb did not light up, students would know that their technique is incorrect, and the injection was "unsuccessful".

Augmented reality technology and the IAN LA simulator

However, the fact remains that students cannot see within the deeper structures of the oral anatomy prior to the injection procedure, which is the exact problem they face with a patient's mouth. To help students more effectively visualise the direction and approach of the needle towards the target nerve site, augmented reality (AR) technology was incorporated with the physical 3D printed simulator (Figure 2). A mobile phone camera was placed a short distance behind the simulator. A virtual image of the injection needle would appear on the phone screen as it moves towards the target nerve site. The student sees the location of the virtual needle, and relates it to the physical location and depth of the needle in the course of delivering the injection. If the needle tip "hits" the correct nerve site, the corresponding site on the phone screen changes colour. The student will be able to see how deep the needle has penetrated beneath the silicone surface. The AR technology enables students to have a visual of the needle's orientation and depth of penetration; at the same time, they are also aware of the needle's actual depth and orientation on the physical simulation model.

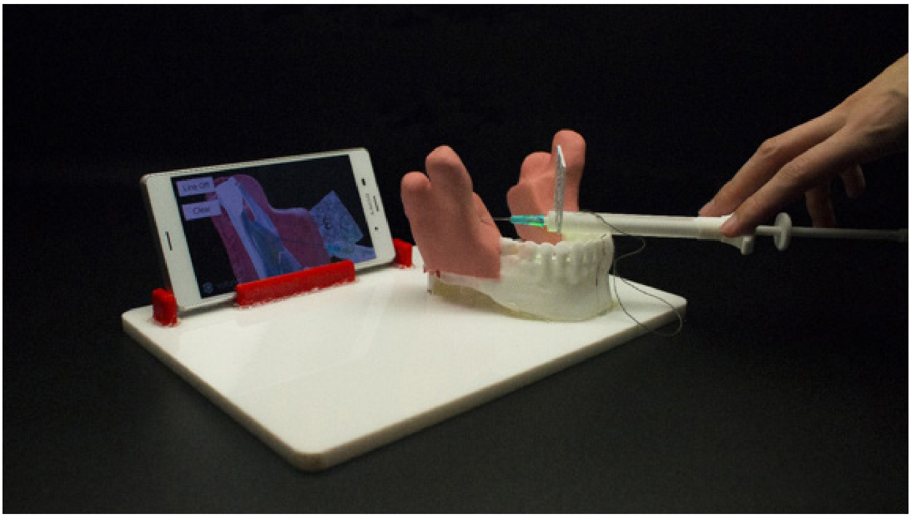

Figure 2. Augmented reality technology combines with the 3D printed simulator for better visualisation of the placement of the needle during IAN LA training.

FORMATIVE FEEDBACK: AN IMPORTANT FEATURE OF THE IAN LA TRAINING

According to Hattie (1999), feedback on students' performance is "the most powerful single moderator that enhances achievement". In a lengthy discussion on the topic by Shute (2008), formative feedback serves to (i) indicate a gap between the desired performance and the actual performance of a task; (ii) functions as a component of instructional design, as reported by Sweller, van Merrienboer, and Paas (1998, page 259), to reduce "extraneous cognitive load" of novices or poorly performing students; and (iii) is useful when it comes to correcting "inappropriate task strategies adopted for a performance of a task". In the article "The Power of Feedback" by Hattie and Temperley (2007), feedback on task performance (in this case, delivering the IAN LA injection accurately) is effective when it is directed at the task and the process to complete the task that results in self-regulation of learning.

Three elements of formative feedback were provided to students when they practiced on the IAN LA simulator, which collectively helped to build confidence and capability:

1. feedback from the instructor while they performed the injection procedure.
2. feedback from the light bulb if the injection was "successful"
3. feedback from the phone screen with the AR technology regarding the depth and orientation of the needle.

Students' views on the usefulness of the IAN LA simulator

A group of 51 Year 2 dental students experienced the IAN LA simulators, and we collected their thoughts on the extent to which the simulators assisted their learning. According to the feedback collated, 78.4% of the respondents (n=40) mentioned that they benefited from the simulators.

The following qualitative comments were taken verbatim from the feedback forms. Respondent 1 stated that "the model assisted my learning as I was able to visualise where my needle was going inside". Respondent 2 felt that the simulator "relates the position of needle and helps me to imagine the mouth better and to position myself better around the patient". The visualisation of the needle position in relation to the injection site is the commonest advantage, 37.3% (n=19) of using the IAN LA simulator. Respondent 3 stated that "it provided [a] visual that would otherwise not be visible and improved the speed of learning." When asked if their levels of confidence increased or decreased after trying the simulator, the mean increment of their confidence was 1.29 (SD=0.94) out of a scale of 5. This was an encouraging feedback from students on the usefulness of the simulators.

Potential from this TEL development

From a broader pedagogical perspective, the reach of this project is immense. The development and testing of this learning platform is an essential move towards a technology-enhanced education. This project permits educators and students to explore novel approaches to teaching and learning respectively, and to acquire 21st century skills for the global knowledge economy. The opportunities from this project expose students to new forms of teaching with emphasis on higher surgical skills development and collaborative/team-based learning for operative procedures. At the curriculum level, this project is about a rethink of the way educators design the dental curriculum, and deliver lessons in a technological context where students can practice and assess their learning through feedback channels which are in line with expertise development. This project has the potential to assist educators involved in the developing, implementing and evaluating of TEL projects to improve their capacity to effectively integrate technology into curricula and instruction. Likewise, it has the potential for broad programmatic application across other healthcare disciplines and professions, and provide enhanced student support which is essential for the targeted programme re-design of courses, particularly for large classes. Collectively, this project has the potential to create novel educational products that demonstrate enhanced learning in NUS and other higher education institutions, in recognition that technology is a driving force in workplaces in the 21st century.

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Kelvin Foong is an Associate Professor and Director of the Discipline of Orthodontics and Paediatric Dentistry in the NUS Faculty of Dentistry. He teaches orthodontics at the postgraduate and undergraduate levels and has been the Director of the Orthodontics Residency Programme since 2000 which trains future specialists in orthodontics, and is also serving as the Module Coordinator for undergraduate Orthodontics. His academic interests focus on decision-making. In education research, he explores the cognitive factors influencing the transition in learning from novice to expertise, as well as medical imaging. He works with a multi-disciplinary team to develop virtual patient-specific anatomic models to facilitate sound clinical-decision making.

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