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A Custom Haptic Syringe to Improve a VR Local Anesthesia Simulation for Foundational Dental Education: A Feasibility Study

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Abstract

Introduction: This paper presents the design, development, and usability evaluation of a custom haptic syringe aimed to improve the realism of a virtual reality local anesthesia simulation (VRLA), specifically for the inferior alveolar nerve block (IANB), that formally used a head mounted device (HMD) and vibration feedback via hand controllers. The custom haptic syringe interface provides a more realistic tactile sensation of plunging a real syringe in a human patient. This pilot study investigated the usability of the custom haptic syringe to replace one of the hand controllers to provide a more realistic and better training experience. **Method:** A one group pre-post survey investigated student perceptions regarding the effectiveness and usability of a haptic syringe to provide a more realistic experience to train dental students to learn the procedural steps to inject local anesthesia into a virtual patient. Twenty-two third year dental students participated. The pre-post survey examined changes in students' perceived emotions, preparedness, and effectiveness of the VRLA as a foundational learning strategy prior to entering clinical group practice. **Results:** While quantitative results on comparable survey questions did not yield statistically significant differences, qualitative open-ended responses revealed a much greater satisfaction using the custom haptic syringe compared to the out of the box controllers. **Conclusions:** Feedback regarding the haptic syringe showed a substantial step closer to providing a more real experience for students in an effort to create a better bridge between classroom learning and clinical practice in order to prepare students to more confidently and competently work with real clients. Further refinement of the syringe is forthcoming along with a more formal comparative experimental study.

Keywords

Haptic Technology, Virtual Reality, Simulation, Local Anesthesia, Authentic Learning, Immersive Learning

1. Introduction

The goal of dental education is to prepare students for independent clinical practice [1]. Dental students need to learn basic procedural skills that require a certain proficiency level of manual dexterity to use instruments to complete common but high-risk tasks such as the inferior alveolar nerve block (IANB). These motor skills are usually introduced in simulation laboratories during the first two pre-clinical years and refined later in clinics with real patients under faculty supervision. The transition from classroom learning to the clinical environment is stressful for dental students as most feel unprepared, anxious, and incompetent, and lack confidence for clinical practice [2]-[5]. As a result, dental training programs are continuously challenged with how to best teach technical motor skills that prepare students for eventual practice [6].

Virtual reality (VR) simulations can help students integrate didactic knowledge with fine motor skills prior to clinical patient care [6]-[8]. The role of feedback on a learner's performance, especially with motor skills, is critical for effective learning [6]-[8]. Haptic technology can enhance VR, replicate realistic experiences for learners, and provide tactile feedback unlike other methods traditionally used to teach technical skills to novice students [6] [9] [10].

In 2020 a team of subject matter experts, designers, and developers at New York University created a bespoke virtual reality local anesthesia simulation (VRLA) to provide students more opportunities to practice and learn the IANB procedure in order to build a stronger foundation prior to clinical practice with real patients. Using a head mounted device (HMD) namely, the Oculus Quest 2 headset and hand controllers, the VRLA simulation immerses the student in a typical clinical office equipped with interactive armamentarium, dental chair, and complete anatomical head to practice the IANB procedure. Prior research on this custom VRLA experience demonstrated that it complemented traditional manikin training and may even surpass the manikin training with improved haptics to make the experience more realistic beyond the out of the box hand controllers [4]. Custom haptic technology can enhance VR simulations with sensory (tactile) feedback allowing the learner to feel and touch with more realism—the focus of the present study.

These findings led to the design and development of a custom 3D printed haptic syringe to elevate the virtual training experience. The main research question for the present pilot was: How do students perceive the usability and learning effectiveness of the new custom haptic syringe compared to the out of the box hand controllers used with the VRLA to prepare them to work confidently and competently with a real patient in a clinic?

2. Literature Review

2.1. VR Simulations and Technology for Pre-Clinical Training

While no single preclinical training program parallels learning on a real person using real instruments in an authentic environment, the goal is to get as close as possible in order to build self-efficacy with minimal risks prior to entry into independent clinical practice [5]. Processing, synthesizing, and integrating information over different time periods is challenging and creates an educational gap between classroom and clinic. Simulation labs with plastic manikin heads allow students to practice injections using real instruments; however, they lack realism as compared to real-life clinical situations [1].

Employing a learner-expert model where the expert observes the learner and then provides feedback compounds the challenge to provide sufficient practice opportunities to every student under supervision as well as the ability of the expert to provide objective feedback with fine granularity [9]. In some programs, students may receive only one or two lab training sessions during pre-clinical years to practice performing local anesthesia injections on a plastic manikin [5]. Students reported feeling unprepared to treat patients after limited practice on lifeless plastic manikins [2]. Manikin training facilitates learning but fails to improve confidence [2]. Such challenges led educators to seek out alternative solutions, namely, VR [11].

VR simulations immerse learners in a multisensory experience replete with numerous advantages such as: making hidden anatomy visible, providing for self-paced and unlimited attempts to practice, giving standardized feedback, and being assessed objectively [6] [12] [13]. Several studies have shown evidence for its use in dental simulations [14]-[16], whereas other studies show mixed results [12] [17]-[19]. Fidelity with haptics likely plays a particularly important role in the success of educational VR simulations [9].

2.2. Haptic Feedback Technology for VR Dental Simulations

"Haptic" refers to the perceptual sense of touch and manipulation [20]. Haptic feedback technology provides the illusory sensation of touching substances and feeling forces [20]. An IANB training study evaluated a mixed reality haptic model (group A) and student-to-student training in a lab model (group B) [5]. Researchers reported that students trained with the simulator performed statistically significantly better than those in a lab evaluated by faculty [5]. It is unclear if group A performed better with additional training as compared to group B. Future study protocols will evaluate an equitable comparison between groups with or without feedback.

Evidence for VR simulations using VR headsets and hand controllers compared to plastic manikins with real instruments in one study showed statistically significantly higher performance scores for plastic manikin training [4]. Other studies comparing haptic-enhanced VR simulations to plastic manikins also show similar outcomes for both [21]. Most published studies regarding haptics for VR in dental education only present findings on student responses and perceptions [9] [22]. One scoping review concluded that haptic simulations are useful for skill building and complement the use of manikins [8]. Despite the need for more research comparing VR haptic technologies and strategies, it appears to be evolving to meet demands of an innovative educational landscape [8].

VR simulations delivered through VR headsets with hand controllers have their own limitations insofar as the hand controllers do not feel like authentic instruments. Haptics through hand controllers delivers a lower fidelity experience as one cannot feel the movement or force feedback of a syringe during aspiration or upon different anatomical structures during injection. Those dental simulators that can deliver force feedback through haptics still may not deliver the level of force that meets realistic expectations compared to real surgery [9]. In contradiction to fidelity is the stable running of the haptic device with high update rates that require simplifications to the force model thereby weakening the fidelity level [9]. The result produces a discontinuous force feedback and vibration that may unintentionally mislead students during training and clinical practice [9]. Given all of these challenges, on-going efforts to improve VR simulations with haptic technology are currently underway [9].

2.3. Theoretical Framework

Deciding to use virtual reality simulation as a teaching and learning strategy is grounded in Situativity Theory which advocated for immersing learners in realistic situations and assigning meaningful tasks with an integrated set of skills [23]. The 3D fabricated environment should simulate reality with a balance of cognitive load and motivation [23]. Working memory is limited to processing elements sequentially and multimedia information can diminish its effects due to cognitive loads and cause inferior outcomes [24]-[26]. For example, by presenting and interacting simultaneously verbal and non-verbal information might increase extraneous load and lead to inferior learning outcomes [24]. Additionally, the student may not develop a meaningful understanding of the content if they are not emotionally engaged or connected to the material [27]. For example, a 2D simulations using images and displayed using a web-browser may be considered less authentic leading to less optimal learning because the student may not feel as connected to the content and thus learn less whereas a 3D immersive simulation of a real clinic with instruments to perform procedures may allow the student to feel more authentic and thus connected to the experience thereby increasing the likelihood of learning.

Prior research investigated authenticity and effectiveness [28]. Outcomes showed the greatest educational value was linked to the realness of the experience [28]. What separates VR simulations apart from other simulations, particularly with the use of head mounted devices (HMD), is a higher level of immersion and presence that approximates direct interactive work. But, understanding the affordances of HMD technology sheds light on how it presents higher levels of authenticity for this kind of immersive experience.

Head mounted devices (HMD) enable users to immerse themselves physiologically. Interactivity is "the extent to which users can participate in modifying the form and content of a mediated environment in real time" [29]. Vividness is "the representational richness of a mediated environment as defined by its formal features, that is, the way in which an environment presents information to the senses" [29]. Immersion has a substantial moderating effect on learning [30]. Research has shown that authenticity and the quality of immersive experiences affect motivation and influence outcomes [31]. The presence of being in a physical place is more likely to be experienced in an immersive environment [32].

The authors selected an HMD VR technology to present a 3D simulation with a custom 3D printed syringe that is connected to a haptic device as an authentic pedagogy. It immerses the student in a realistic environment and situation. The *immersive* quality of VR with HMD with authentic haptics provides the student with a *vivid* three-dimensional space and also a tactile experience that fully engages the student's senses, feelings, and mind to further increase the feeling of *presence*. The VRLA was designed to position the learner as an *interactive participant*, with greater control over the experience.

3. Methods

3.1. Study Design

This pilot usability study was approved by the University's Internal Review Board. The study was conducted in 2023 at New York University. It used a one group pre-post survey design to evaluate the usability, report positive and negative aspects, and provide opportunities for further improvements of the custom haptic syringe.

3.2. Participants

Twenty-two dental students volunteered and consented to participate. For a usability study at least twenty participants for quantitative data and at least eight participants were needed particularly for the qualitative data. All participants had prior experience with the VRLA simulation using out of the box hand controllers. Prior research conducted by the authors already concluded that the out of the box controllers were challenging to use and detracted from the authenticity of the experience [4]. Repeating the VRLA experience with out of the box hand controllers with new students would not have provided any new information. We chose to include students who had already used it with the out of the box hand controllers so that we could get their experienced feedback on the new custom haptics.

3.3. Instruments

Instruments included an online pre-treatment survey, one practice treatment with the custom 3D printed haptic syringe connected to a Geomagic Touch™ device in the dominant-hand and the original VRLA simulation and Meta Quest Pro headset with one hand controller in the non-dominant hand, and an online post-treatment survey. Survey items used a mix of 5-point Likert-type scales, multiple choice and open-ended questions in **Table 1A** (Appendix).

3.3.1. Pre and Post Simulation Survey Materials

The pre-simulation survey contained fifteen questions crafted by authors of this study; two single select, five open-ended, one multiple select, and four Likert scale questions (five point). The questions focused on demographics**,** prior local anesthesia, VR technology, VRLA experience, and feelings towards administering local anesthesia on patients. The post-treatment survey repeated seven questions from the pre-survey for comparison and are denoted with an asterisk in Table 1A (Appendix). Analysis of these questions focused on comparing the VRLA experience with hand controllers in both hands to the VRLA experience with the haptic syringe in the right hand and one controller in the left hand. All questions were crafted by the authors.

Since the cohort used the survey at two different times we conducted a test-retest reliability statistical measure to report the reliability for items using five-point scales (#9, #13, #14 and #15). Individual items with acceptable to good alpha levels include #9 = 0.777, #13 = 0.794, #14 = 0.881, #15 (Anxious) = 0.830, #15 (Stressed) = 0.902, and #15 (Indifferent) = 0.721. Individual items with low reliability include #15 (Excited) = 0.371, #15 (Confident) = 0.632, and #15 (Competent) = 0.458.

3.3.2. VRLA Simulation Treatment with Commercial Hand Controllers

A team of experts developed the VR Local Anesthesia simulation. The original application is experienced with a VR headset and two hand controllers as a pre-clinical simulation system that leverages the advantages of VR-based, interactive systems (**Figure 1**). It provides a self-paced learning environment that is realistic and immersive with opportunities for unlimited practice and multimodal feedback. The simulation also displays highly detailed views of the anatomy. This is important knowledge that students must be proficient in to be competent. Students can practice anywhere as it is affordable and transportable.

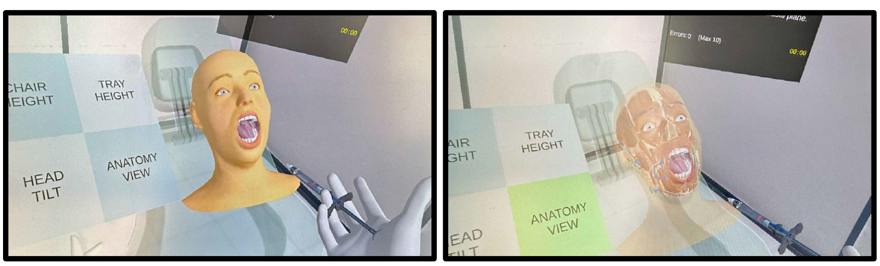

Figure 1. VRLA Simulation.

The dental office, chair, and instruments were rendered to accurately represent what is currently available in the clinic with a high degree of fidelity. All of the tasks in the original VRLA simulation rely on hand controllers to adjust the tray height, aspirate, apply topical anesthesia, and use the transparency feature to see hidden anatomical structures. Using simulated hands guided by hand controllers, students set up their tray with appropriate instruments and materials for the procedure and assemble the carpule and syringe. The simulated hands directed by the hand controllers perform all of the steps for the IANB (inferior alveolar nerve block) injection procedure including: retracting soft tissues and visualizing the injection site, positioning of the syringe and orienting the needle, puncturing the musculature and contacting the mandible, aspirating to rule out an intravascular injection, and timing rates of injection.

The user presses the grip button of the controller in their non-dominant hand to retract the cheek and uses the controller in their dominant hand to press on the trigger button to perform the injection. Haptic feedback as vibrations signals the student when they contact the bone. With the VR headset, students see their virtual hands holding a syringe and retracting the cheek but haptically feel the hand controllers and press buttons to perform the steps (**Figure 2**).

Figure 2. Commercial headset and hand controllers by Meta™.

3.3.3. VRLA Simulation Treatment with Custom Haptic Syringe

The design methodology for the syringe interface is shown in **Figure 3**. The workflow can be separated into an input, four design stages, and an output. The input is the desired profile where the force profile for the syringe interface is determined. The output is the completed device. The four design stages are origami pattern generation, pattern analysis, prototyping, and haptic characterization.

The desired profile defines design constraints that are largely dependent on the intended application of the haptic interface. These constraints are closely related to the geometric nature of origami itself, and are thus achieved by adaptation of geometrical transformations. The constraints also tie in with material considerations of the physical origami implementation. The thickness of the origami material used can control stiffness. More importantly, there are design constraints for achieving certain haptic characteristics. The exertable force attributes will play a big role in the force capabilities of the design, so physical attributes such as inertia and stiffness are important design constraint considerations. The maximum recorded pressure measured in Carpule syringes during the application of local anesthesia is around 2000 mm Hg (266.5 kPa). Based on a typical piston surface area of 6 mm2, the steady feedback force generated by pressing the plunger and the syringe piston against the anesthetic fluid is around 1.6 N. Accordingly, we need to design a Kresling spring that can generate a force-displacement profile that has a steady force value within an acceptable tolerance from 1.6 N.

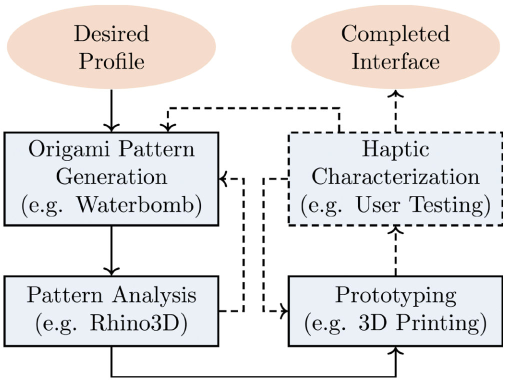

Figure 3. Syringe design methodology.

After formulating the desired input profile, we used an origami-inspired spring based on the Kresling origami pattern [33]. Among many of the unique properties of the Kresling origami spring, one of its main features is its high tunability [34], which enables one to tailor the force displacement profile by simply tweaking the geometric design parameters, achieving different spring behaviors. A spring formed by the Kresling origami pattern consists of triangular panels arranged in cyclic symmetry and attached to top and bottom rigid polygon planes. The design parameters that alter the spring behavior are the initial height (Uo), the initial twist angle between the top and bottom polygons (ϕo), the radius of the circle that circumscribes the polygons (R), their number of sides (n), thickness (t), and the width of the creases (W). For the application at hand, we are interested in the origami springs that can realize the QZS behavior, since it exhibits a flat (constant) force regime emulating the force profile of a Carpule syringe. A finite element computational model of the Kresling origami spring including transient behavior is developed using COMSOL Multiphysics. Using the computational model and calibrating the geometric design parameters, we were able to obtain a spring that possesses the desired force profile. The design parameters that produce this spring are: (N = 6, R = 10 mm, Uo = 9 mm, ϕo = 52.5, t = 0.75 mm, and W = 1 mm).

The Kresling origami spring is fabricated by utilizing the multi-material 3D printing capability of the polyjet technology using a Stratasys J750 3D printer. The components of the syringe interface are shown in Figure 4(a). The origami springs were connected with thin rings to form the origami stack, keeping them aligned in the left and right enclosures and connected to the holder cap and plunger. These parts were 3D modeled based on the stack dimensions and printed using selective laser sintering (SLS) on the EOS Formiga P110 using the Polyamide 12 nylon powder. The key dimensions for the models are shown in the figure (Figure 4(a)). The enclosures also come with a 6.3 mm audio jack socket that connects the syringe to the Touch haptic device. In addition, a holder cap fits in the plunger and the origami stack. These components are secured together once the right enclosure is screwed into the left enclosure, which results in Figure 4(b). The position of the plunger is tracked using a 100 mm linear soft potentiometer to monitor the injection. Two low-stiffness pogo pins are attached to the holder cap to slide along the soft potentiometer. To complete the interface, the potentiometer was connected to an Arduino microcontroller, which in turn was connected to the VR simulation computer through its universal serial bus (USB) communication. The VR simulator is displayed via a VR headset. Note that a 0.3 N anti-gravity force is rendered by the Touch haptic device to compensate for the weight of the syringe interface.

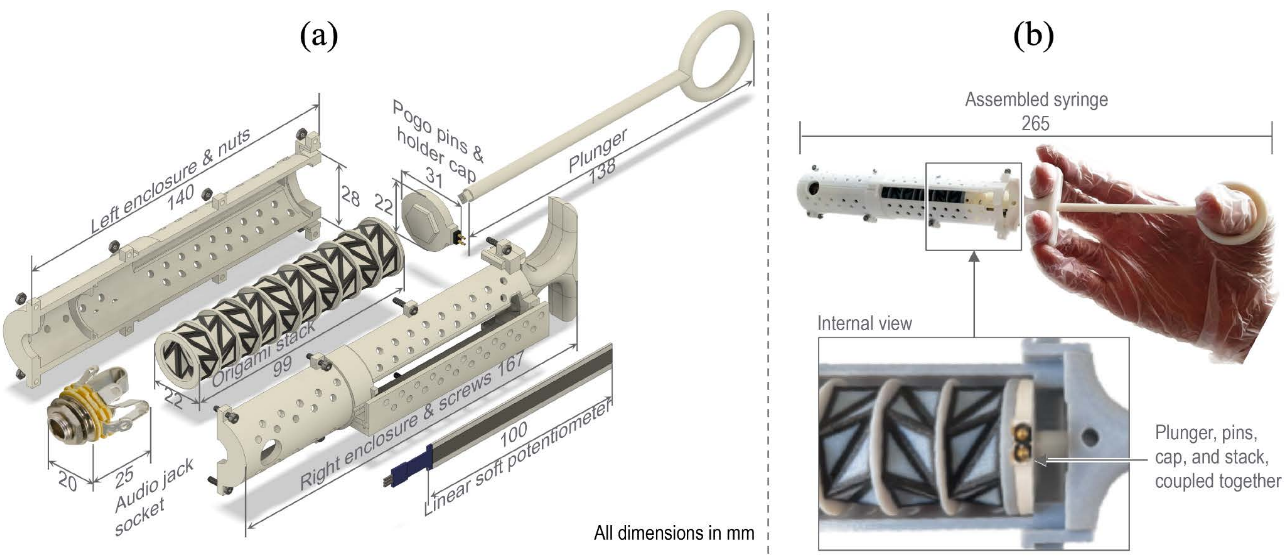

Figure 4. Syringe interface design: (a) The components of the origami-based syringe design & (b) The assembly & its internal view.

After assembling the syringe interface from its 3D printed parts, a series of loading tests were performed to obtain force-displacement profiles for both the single origami cell, the origami stack, and the final syringe interface. The data were then compared with the simulated results for validation, as shown in Figure 5. Additionally, the origami syringe was tested alongside a conventional Carpule syringe to make a direct comparison. These results clearly indicate that the force profile generated by the syringe interfaces perceptually matches the Carpule syringe force profile.

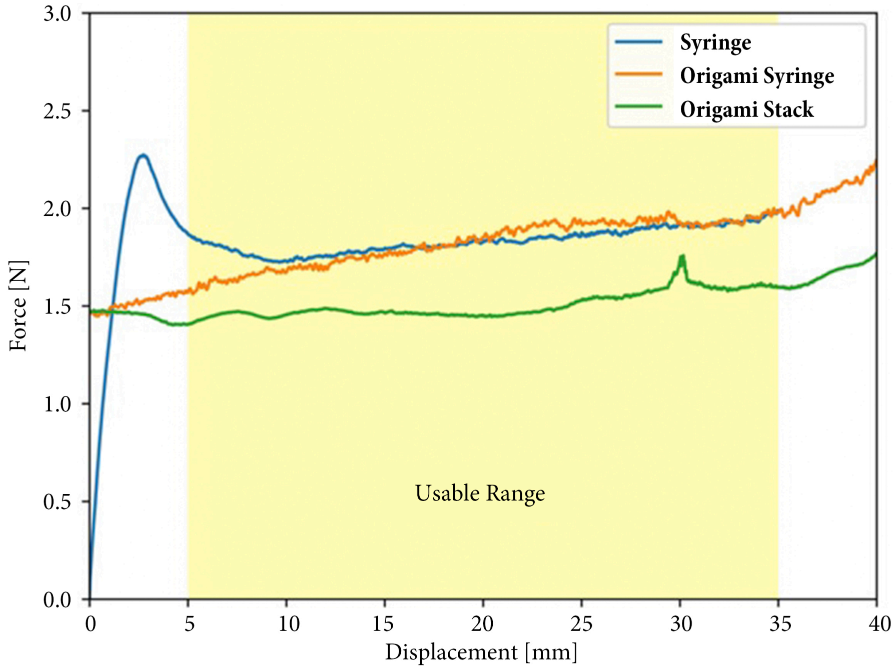

Figure 5. Average plunging force displacement profiles of Carpule syringe, origami syringe, and origami stack.

3.4. Study Procedure

The technology setup is shown in **Figure 6**. Each third-year dental student completed an online pre-task survey prior to their scheduled participation time. Each scheduled session lasted about thirty minutes and took place in a quiet office space. Two researchers attended each session to manage the process. One researcher assisted students with the technology while the other observed and took notes. Each student was introduced to the new technology and given assistance with the headset and new haptic syringe. Each student was instructed to follow the instructions displayed in the simulation and perform the injection steps as per usual but now using the new haptic syringe instead of the virtual hands guided by

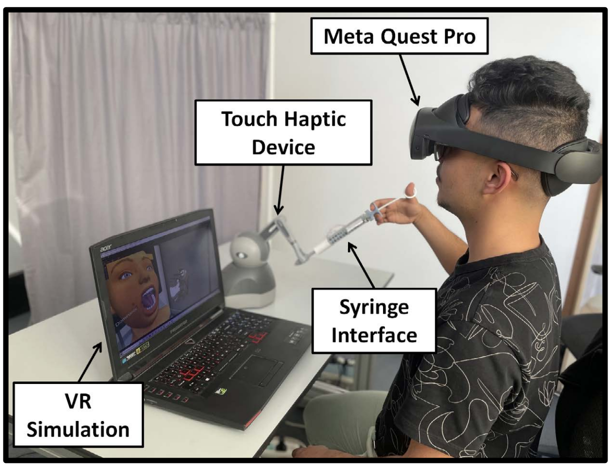

Figure 6. Experimental setup.

the hand controller. After the experience each student was asked to provide verbal feedback to the researchers and complete an online post-task survey.

3.5. Data Analysis

To address the research question, the quantitative pre and post survey data analyzed descriptive statistics, mean (M) and standard deviation (SD) and inferential statistics, independent t-tests. A text analysis methodology of topics was used to explore the short follow up responses to open-ended questions in order to further explain and contextualize the quantitative results. Using a text analysis coding method [35], the open-ended follow up questions were analyzed by reviewing the raw responses, identifying most used words or phrases, codifying them into meaningful categories (or codes), organizing them in a table according to categories (or codes) and then tabulating the counts. Given the brevity of answers, coding was conducted manually. In order to assure semantic validity more than one researcher reviewed the words or phrases judged in a category to confirm its meaning.

4. Results

4.1. Pre-and-Post Treatment Survey

4.1.1. Pre-Treatment Survey Background Characteristics

Twenty-two third year students volunteered and consented to participate in the pilot study. Eight students reported using the pronoun "he" while fourteen reported using the pronoun "she". Nineteen students reported being enrolled in a four-year dental education program and three in a two-year program. The average age was twenty-seven.

4.1.2. Prior Local Anesthesia Experience

When asked the number of live injections students have actually performed on a live patient thirteen reported zero times, eight students reported performing four or more injections, and one student reported having performed it once on a live patient.

When asked to select all the types of injections students have performed on a live patient again thirteen students did not select any of the listed injections, four students selected all the injections listed, and five students selected some of the injections listed. The most selected injections include the IANB (Count = 7), the IANB & Long Buccal (Count = 8), Local Infiltration of the Buccal Tissues (Count = 8), and Local Infiltration of palatal/lingual tissues (Count = 9).

4.1.3. Prior VRLA Experience

Previous Experience with the VRLA Simulation.

All D3 students reported having previously used the VRLA simulation. In response to the Likert scale question regarding the number of times students used the original VRLA simulation with Oculus Quest 2 headset and hand controllers, seventeen students reported using it once, two students used it twice, two students used it three times, and one student used it five or more times.

VR Technology Experience Rating.

In response to the Likert scale question regarding student's personally rated experience level using the VR technology such as Oculus Quest 2 headset and hand controllers, seven students reported being novices, nine students reported being advanced beginners, five students reported being competent users, and one student reported being an expert.

4.1.4. Pre and Post Treatment Survey Comparison

The seven comparable questions in the surveys focused on the different VRLA experiences with VR technology. The pre-treatment survey asked about the original experience using the Oculus Quest 2 headset and two hand controllers. The post-treatment survey focused on the VRLA experience using Meta Quest Pro headset with the new haptic syringe and one controller.

VRLA Simulation Task Completion Rating.

When asked about students' perceived ability to perform tasks in each respective experience, the responses were at a very similar average range, *moderately well* (pre mean = 2.64 (SD = 0.902); post mean = 2.95 (SD = 1.174)).

VRLA Simulation Training Effectiveness.

When asked about students' perception of preparedness for patient interaction, the average responses for both were somewhat *effective* with respect to both experiences (pre mean = 3.14 (SD = 0.941); post mean = 3.18 (SD = 0.958)).

Feelings to Perform in the Future.

When asked about certain words describing feelings to perform the injection on a patient in the future, responses for both experiences were close in averages and not statistically significant (Table 1).

Table 1. Pre-post feelings.

Feelings To Perform Injection	Pre (VRLA with 2 Hand Controllers) Mean (SD)	Post (VRLA with 1 Haptic Syringe & 1 Hand Controller) Mean (SD)
Anxious	3.14 (1.5)	3.18 (1.37)
Stressed	3.36 (1.43)	3.32 (1.39)
Excited	2.41 (1.01)	2.41 (1.01)
Nervous	3.64 (1.23)	3.77 (1.15)
Confident	3.05 (1.21)	2.50 (1.44)
Capable	2.91 (1.11)	2.45 (1.14)

Easiest Task.

In the open-ended response in the pre-survey regarding the easiest task to perform with the VRLA using hand controllers, the answer was visualizing anatomy (Count = 7). Examples include visualizing the procedure, landmarks, nerve, anatomy, and transparency features aiding in this process. The next easiest task was grabbing and placing objects using hand controllers (Count = 6) and specifically as it relates to setting up equipment (Count =4). Lastly, students found following instructions, reading them, and the simplicity of setting up the armamentarium easy (Count = 4).

After using the custom haptic 3D syringe, students shifted their responses in the post-survey and they most commonly reported the easiest task was controlling the syringe compared to the hand controllers (Count = 10). They appreciated the realism of the syringe-shaped device, which felt more intuitive and similar to real-life procedures. This is a shift where performing the injection itself is usually the most difficult task and setting up the armamentarium tray is the easiest one. Participants also mentioned the life-like feel of the syringe and the feedback they received while using it (e.g., insertion into soft/hard tissues). They noted this as a major improvement over generic hand controllers (Count = 5). Users found it easy to identify anatomical landmarks and deliver anesthesia in the simulation, especially with the custom syringe controls (Count = 4). The syringe-shaped device provided a more natural and intuitive experience compared to the usual joystick or controller setup in the VR environment (Count = 3). Users also highlighted that picking up and manipulating the syringe, and other instruments felt more comfortable and intuitive during the simulation (Count = 2). Overall, the control of the syringe was considered the easiest and most intuitive part of the VR simulation, with feedback emphasizing the realistic feel and improved interactivity compared to standard controllers.

Challenging Task.

In the pre-survey, the majority of students reported that the most challenging task to perform in the VRLA with hand controllers was controlling or steadying the needle, handling anesthetic materials, and maintaining proper positioning of the virtual syringe using hand controllers during injections. (Count = 8). For example, one student typed "It was hard to control. Holding the needle and anesthetic materials was difficult. Overall, controlling things over was hard." Students also found aspiration and the injection process difficult, including the delivery and the sensitivity of positioning during the anesthesia administration (Count = 4). Students also reported that the lack of realistic tactile feedback such as pressure during injection contributed to errors (Count = 3). Struggles with finding the correct angle or position for needle insertion, as well as adjusting the syringe's angulation were also noted (Count = 4). The need for precise needle placement and positioning that aligns with the VR program's recognition was also noted (Count = 3). Overall, the key challenges appeared to revolve around control of tools, lack of tactile feedback, and the precision required during the procedures.

In the post-survey, after using the haptic syringe, students' responses shifted from the focuses in the pre-survey. Retracting the cheek during the simulation was a common challenge because they were still holding the hand controller in the non-dominant hand. Users found it difficult to hold and maneuver the cheek while performing the procedure, which affected their ability to visualize landmarks and inject accurately (Count = 5). Several participants had difficulty controlling the needle, either because it didn't sync properly with the VR display or because it moved after penetrating the tissue, making it hard to maintain a steady position (Count = 4). Users expressed issues with the lack of haptic feedback from bones and tissues, leading to the needle passing through unrealistic barriers like bone. They also found it hard to gauge the proper resistance when pushing the anesthetic solution in place (Count = 4). Lastly, there were challenges in maneuvering the syringe and controllers precisely, including adjusting the bevel, maintaining steady movements, and delivering anesthesia accurately (Count = 3).

Improvements.

In the pre-survey, the open-ended response question requested suggestions for improvement centered on tactile feedback and haptics (Count = 6). Participants suggested adding haptic feedback or resistance to simulate real-life tactile sensations during procedures, such as injecting into tissue or hitting bone. For example, one student commented "I would add some resistance to give us the feeling of what injecting into tissue would feel like, then hitting bone." Other students suggested improving control over movements and reducing sensitivity in the system, as some users found the VR too sensitive or unresponsive (Count = 5). Lastly, students suggested feedback for a handheld retractor tool for cheek retraction with hand controllers, and using more realistic tools like a syringe shaped controller (Count = 2). Overall, the most common feedback was the need for better tactile feedback, improved control and sensitivity, and more instructional guidance to enhance the VR experience.

In the post-survey, users requested more refined haptic feedback, both in terms of better tactile responses from soft and hard tissues (e.g., needle not passing through bone) and resistance during procedures like retraction and penetration (Count = 5). Suggestions were made for cheek retraction improvements, such as making it stay in place and enhancing visibility, especially for viewing certain teeth, like the lower premolars (Count = 3). Improvements in needle control and sensitivity were requested. Some users also wanted smaller and lighter syringe models for better handling, along with improved calibration and minimized movement after mucosal penetration (Count = 4). Making the model and overall environment more realistic was a common suggestion. This includes aligning the virtual syringe's movements with physical actions and making the simulation more lifelike (Count = 3). Lastly, there were suggestions for adding the flow of aspiration and making the process of injecting and overcoming mistakes more realistic (Count = 2). Overall, the most frequently suggested improvements focused on better haptic feedback, enhanced cheek retraction and visibility, and more realistic syringe control and calibration. Error handling, visual realism, and polished usability were also commonly highlighted areas for enhancement. All suggestions will be considered in forthcoming improvements.

5. Discussion

The successful and safe delivery of local anesthesia requires the integration of knowledge and fine motor skills [1] developed through deliberate practice [36]. It is challenging to learn and perform tasks with real instruments on patients [1]. Feedback provided in the pre-survey and prior research [4] communicated the desire for realistic tactile feedback and haptics for fine motor skill training. While quantitative survey questions showed averages supporting the custom haptic device they did not yield statistically significant results between pre and post treatment survey questions. However, responses from open-ended survey questions were promising. Student feedback showed that the custom 3D printed haptic syringe interface improved the learning experience with a high degree of realism and tactile response. It also showed the need for custom haptics in the non-dominant hand to compliment the achieved realism.

Most promising were the responses from open-ended survey questions. Student feedback in the open-ended responses showed that the custom 3D printed haptic syringe interface improved the learning experience compared to the out-of-the-box hand controllers with a higher degree of realism and tactile response. As reported by students in both surveys, performing the IANB was a challenge to perform with the hand controllers and with the haptic syringe but the haptic syringe was easier to use and more realistic compared to the hand controllers. Responses by students regarding challenges with the haptic syringe became more specific to the experience likely because they were using a real instrument. The haptic syringe provided varying degrees of haptic force to mimic aspects of the procedure such as penetrating the mucosa, hitting bone, and the force to deliver the anesthesia by pushing the thumb ring down. As a feasibility study, the direction of a 3D printed haptic syringe showed that it is a viable improvement over the hand controllers.

6. Conclusion

This feasibility and usability study aimed to confirm the engineering direction during the first phase development and to determine if a custom haptic syringe would improve a VRLA simulation to provide a more realistic experience for fine motor skills training as compared to the standard hand controllers. The feedback from students confirmed the engineering direction of the haptic technology to pursue further and refine the experience in future phase development cycles. Feedback was positive, constructive, and encouraging. Future improvements to the haptic syringe will include optimizing the device weight, size reduction, and adding further haptic features (such as aspiration simulation). Furthermore, developing a haptic device to simulate cheek retraction via the non-dominant hand will also be forthcoming.

7. Limitations & Future Studies

This pilot usability study used a one group pre-post survey design and may be vulnerable to biases. Self-reported data may show inconsistencies and bias. Future studies will aim to evaluate the custom haptics at the final stages of phase development using efficacy research methods. It will also include at least two groups for comparison with a control group and a cognitive assessment to measure learning gains between the two groups. Future studies will aim to address these limitations.

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Data Availability

Data supporting the findings of this study are available from authors upon reasonable request.

Conflict Of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table 1A. Pre-post treatment survey.

Item	Question	Response Type
1	Select your current status. I am a ...	Single Select
2	What is your current age (e.g., 18, 19, 20, 21, 22)? Please type in your answer:	Open Ended
3	Which pronoun do you primarily use for yourself (e.g., he, she, they, ze, xe...)? Please type in your answer:	Open Ended
4	How many times have you performed Local Anesthesia on a live patient?	Single Select
5	What type of injection/s have you performed on live patients? Select any choices that apply	Multiple Select
6	How would you rate your experience/ability using Virtual Reality technology such as a headset with controllers to experience an immersive world?	Likert 1 = Novice 2 = Advanced Beginner 3 = Competent 4 = Proficient 5 = Expert
7	Have you ever used the Virtual Reality Local Anesthesia Simulation offered at NYU College of Dentistry?	Yes/No
8	How many times have you used the Virtual Reality Local Anesthesia Simulation offered at NYU College of Dentistry?	Single Select
9*	Overall, how well do you think you achieved the tasks using the Virtual Reality Local Anesthesia Simulation?	1 = Extremely Well 2 = Very Well 3 = Moderately Well 4 = Slightly Well 5 = Not Well At All
10*	What did you find the easiest to use/do within the Virtual Reality Local Anesthesia Simulation?	Open Ended Response
11*	What did you find to be the most challenging to use/do within the Virtual Reality Local Anesthesia Simulation?	Open Ended Response
12*	What would improve the Virtual Reality Local Anesthesia Simulation? What features would you add or remove?	Open Ended Response
13*	How effective do you feel the Virtual Reality Local Anesthesia simulation has prepared you for treating live patients with local anesthesia?	1 = Not At All Effective 2 = A Little Effective 3 = Somewhat Effective 4 = Very Effective 5 = Extremely Effective

Continued

14*	How prepared do you feel to perform local anesthesia injection on live patients?	1 = Not at All Prepared 2 = A Little Prepared 3 = Somewhat Prepared 4 = Very Prepared 5 = Extremely Prepared
15*	To what extent do the following words describe your feelings to perform an IANB injection on a live person in the future? Anxious Stressed Excited Indifferent Confident Competent	(Matrix) 1 = Very much describes my feelings 2 = Describes my feelings fairly well 3 = Somewhat describes my feelings 4 = Does not describe my feelings much 5 = Does not describe my feelings at all