The Utilization of Mixed-Reality Technologies to Teach Techniques for Administering Local Anesthesia

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USING MIXED-REALITY TECHNOLOGY TO TEACH TECHNIQUES
FOR ADMINISTERING LOCAL ANESTHESIA

by

Kami M. Hanson

A dissertation submitted in partial fulfillment
of the requirements for the degree
of
DOCTOR OF PHILOSOPHY
in
Instructional Technology and Learning Sciences

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2010
ABSTRACT

Using Mixed-Reality Technology to Teach Techniques for Administering Local Anesthesia

by

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Utah State University, 2010

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The ability to perform local anesthesia on dental patients is an important clinical skill for a dental hygienist. When learning this procedure in an academic situation, students often practice on their peers to build their skills. There are multiple reasons why the peer practice is not ideal; consequently, educators have sought the means to simulate the practice of local anesthetic procedures without endangering others. Mixed-reality technologies offer a potential solution to the simulated procedure problem. The purpose of this research was to determine if students could learn the techniques for providing local anesthesia using a mixed-reality system that allows them to manipulate 3D objects in virtual space. Guiding research questions were: In what ways do using 3D objects allow for a greater understanding of anatomical, spatial, and dimensional acuity? Will students develop conceptual understandings regarding the application of anatomical and technical concepts through iteration? Will students demonstrate the proper technique and
verbalize a level of confidence for administering local anesthesia after using the mixed-reality system? Design-based research methods allowed for multiple iterations of design, enactment, analysis, and redesign. The first iteration focused on building a knowledge base for designing and developing virtual reality technologies for use in dental hygiene education. The second phase of research increased in technical sophistication and involved a virtual system that allowed for student interaction and manipulation of 3D objects. The interactions supported students’ learning through the association of anatomical, spatial, and dimensional acuity. Built-in learner prompts promoted the understanding and identification of anatomical landmarks for performing an injection for the lower jaw. Further, the system promoted self-controlled practice and iterative learning processes. Redesign and development in the final iteration focused on design improvements of the system that included an output metric for assessing student performance, a data glove, and a marker to assist in following student interactions. Results support that students learned “while doing” in a specific immersive environment designed for dental hygiene education and they increased their level of confidence for performing a specific procedure.

(246 pages)
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I would like to thank my family for their undying support of my educational endeavors. I have been in graduate school since I moved back to Utah, and my son, my niece, and my parents have had to sacrifice a lot for me to attain this professional goal. I can never thank you enough. Just know that I am very grateful. I give special thanks to my extended family, friends, and colleagues for their encouragement, moral support, and patience as I worked my way from the initial proposal writing to this final document. I could not have done it without all of you.

I would like to thank my Ph.D. committee for their mentorship and contributions to the success of this project. Thanks to Brett Shelton for supporting and believing in me. He never once told me that I could not do the enormous project that I had envisioned. He took my vision seriously and has had to wade through multiple documents with me during this process. Thanks to Andy Walker and Doug Holton for serving on my reading committee. I know that I asked a lot of you in a tight timeframe. Thank you for your support and suggestions. I want to thank all of you, Yanghee Kim and Oenardi Lawanto, for your willingness to serve on my committee. I know that working with an off-campus student has not been easy. Thank you for not forgetting about me.

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Kami M. Hanson
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The ability to perform local anesthesia on dental patients is an important clinical skill for a dental hygienist. Most dental hygiene curriculum includes didactic and clinical courses on local anesthesia for the oral cavity. The skill of administering local anesthesia includes cognitive abilities, procedural knowledge, and motor skills. In dental hygiene classes, students administered local anesthetic on each other before they were allowed to practice injections on dental patients. Students performed better on dental patients once they had the opportunity to practice on each other and demonstrate competency while not performing patient treatment (Malamed, 2004; Mangan, 2000; Schmidt & Wrisberg, 2004). This hands-on instruction allowed students to base their understandings of anatomical structure and local anesthetic techniques on real world experience.

Concerns have emerged in the dental community, however, about students practicing local anesthetic techniques on their peers and performing injections on live patients for the evaluation of clinical skills, as is the case in local anesthetic licensure examinations (American Dental Association, 2000; Formicola, Shub, & Murphy, 2002; General Assembly of the American Association of Dental Examiners, 2001). Even though widely accepted in the past, the use of live patients for practice is no longer considered ethical because actual anesthetic agents, which introduce potentially toxic anesthetic medication into the bloodstream for a nontreatment purpose, are used. Due to the potential for deleterious physiologic effects, local anesthetic injections are now carefully considered before administering.
Educators have sought other ways to provide a student with a hands-on experience without practicing on real patients. Educational technology researchers who investigate the use of mixed reality suggest a possible alternative to the use of human subjects for the instruction and evaluation of clinical skills (Behrend & Rosenthal, 2007; Cates, Patel, & Nicholson, 2007; Mangan, 2000). Mixed-reality technology allows for an augmented perception of reality where the user can interact with virtual 3D objects in virtual space. Evidence suggests that using a mixed-reality interface to manipulate 3D objects can assist students in making assessments and connections about physical objects in their environment (Bimber & Raskar, 2005; Shelton & Hedley, 2003; Waterworth & Waterworth, 2001). Further, a mixed-reality environment assists the students in their perceptions and understandings of anatomical spatial relationships that are critical for learning the techniques associated with administering local anesthesia and for the completion of other dental procedures that require similar skills.

The purpose of my research was to determine if students are able to learn the technique for providing local anesthesia, which involves cognitive knowledge of physical structures and procedural knowledge, using a mixed-reality system that allows them to manipulate 3D objects in virtual space. The research questions were: In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity? Will students develop a better understanding regarding the application of anatomical and technical concepts through iteration? Will students be able to demonstrate the proper technique and verbalize a level of confidence for administering local anesthesia after using the mixed-reality system? A glossary of words is provided in
Appendix A that may prove to be helpful as you progress through this document and read about cranial anatomy and anesthetic technique.

In this research, the student is engaged in a designed instructional activity using a custom-built mixed-reality system for local anesthesia called the Local Anesthesia Mixed-Reality System (LAMRS). LAMRS offers a mix of the user’s real world combined with a virtual world, thus a mixed reality. An important aspect of the instructional intervention created was that it could be used in the dental operatory. Realizations of real physical constraints, the patient’s head, and the dental chair when performing an injection are integral in the acquisition of motor skills. Based on analysis of student interaction with LAMRS, I present an overview of how their understanding of techniques for local anesthesia changed.

In this introduction, background information is provided on the nature of the problem regarding live patient practice for local anesthesia skills acquisition. Included is an analysis on the importance of the subject and the need to address these concerns at this time. I have included my research purpose and those questions I have sought to answer with my instructional intervention. The rest of this chapter will be an organizational overview of the rest of my dissertation document.

In Chapter II, I present a summary of the proper injection technique for numbing the lower jaw and address the theoretical grounding for this research. A discussion on the challenges that students face in learning to anesthetize the lower jaw segues into the presentation of theories and evidence that support motor skills acquisition and issues of self-efficacy that underlie my research. I present my identification of those instructional
needs that my intervention would need to address. Specifically, motor skills learning is discussed in relation to clinical practice, and the benefits of guided discovery with just-in-time feedback are presented. Specifically, the three stages of motor skills acquisition are aligned with those instructional needs that I have identified. Issues related to self-efficacy are explored with focus on strategies for obtaining increasing levels of confidence. Last, ways of learning in artificial environments and with augmented reality are explored with emphasis on those virtual approaches that have been put into practice.

As summary for this chapter, I demonstrate how my instructional intervention will address learner needs that are correlated with the cognition, association, and automation of motor learning and how I have leveraged the benefits of a mixed-reality environment for this purpose.

In Chapter III, I offer an overview of my virtual system outlining my vision and intent for student learning. I discuss the methodology of design-based research (DBR) as it represents my strategy for the design and development of my virtual system. I had a vision for what I wanted to achieve with my instructional intervention but lacked the knowledge of how to get started. Consequently, I expected there would be multiple iterations in my development with concomitant research phases. In this chapter, I go into detail on design, enactment, analysis, and redesign from Phase I to Phase III, giving specifics for decisions made at each stage. Furthermore, I list specific system components for my virtual system and refine my research goals in the process. I began my research delving into the world of virtual reality (VR) and constructed a rudimentary VR system on a budget of $2,000. I ended Phase III with a more complex understanding
of VR and instructional design and created a sophisticated system that involved expensive hardware and software at a combined budget of $80,000. At the end of this chapter, I provide an analysis of the impact my research outcomes have had on the profession of dentistry and on future uses and creation of virtual systems for educational purposes.

In Chapter IV, I describe the research goals for Phase I and those technology goals that were designed to reach those goals. My research process is defined with a description of results and a discussion of research findings. Specifically, detail is given on hardware and software of the VR system as well as clarification for my decisions. Also, resources are listed for those media utilized to build my knowledge base in order to complete my goals for this phase. The results were a clearer understanding of virtual technology and those components necessary for constructing a virtual system. I was also able to build a simple system using a pattern-recognition rendering system that allowed my student to view my 3D image but could not interact with it. The fidelity of the 3D image at this stage was poor. My intent for my instructional intervention could not be realized with this system.

In Chapter V, I present Phase II of research using LAMRS. Research questions are presented with an outline of methodologies followed by a presentation of results. With a larger budget of $50,000, I was able to construct a more sophisticated mixed-reality system. I present a summary of system components and explain the purpose of these components for my research. Students demonstrated learning with the system even though there were system errors that impeded user presence. Students were able to get a
sense for anatomical relationships and liked that they could see the manipulated views of
the cranial structures while they evaluated the efficacy of their technique. This phase of
research with LAMRS supported cognition and association related to motor skills
learning. Redesign changes are presented with consideration for the next iteration.

Chapter VI represents an overview of Phase III of research. The research
questions are presented in this chapter along with employed methodologies and a
presentation of results and discussion items. I was awarded another $30,000 for system
improvement to LAMRS. The basic system from Phase II could be utilized and
improved upon at this stage. I purchased new hardware that improved the student’s
experience and interaction with LAMRS. An output metric for student performance was
added to the system and explained in detail during this chapter. The result was that all
three stages of motor skills acquisition—cognition, association, and automation—were
supported, an outcome which, in turn, supports my research questions. Students were
able to investigate the 3D image from a first-person perspective and from 360 degrees to
gain a greater understanding of anatomical spatial and dimensional relationships. These
activities support experiential learning, where students construct their own
understandings based on “hands-on” experience. Students were able to practice the
technique for performing an inferior alveolar (IA) (lower jaw) injection with a full
understanding of anatomical landmarks. They were able to make mistakes with LAMRS
and alter their strategies using iterative learning. The use of LAMRS did improve student
confidence for performing local anesthesia, thus providing sage rationale for the
practicality of its use.
In Chapter VII, I provide an evaluation of the entire project. I offer some of the benefits of conducting research on the use of immersive environments for education and provide some philosophical dialogue on potential benefits of moving forward with the application of technology in education.
CHAPTER II
THEORETICAL GROUNDING

Administering local anesthesia requires more than technical skills. It includes interplay between knowledge, procedural skills, and systems aspects of learning. Specifically, students need to possess conceptual competency of anatomy and spatial relationships and then demonstrate this competency in a clinical situation. The use of mixed reality in the promotion of these competencies is the focus of my research and the investigation to the potential degree that mixed reality has for the clinical practice of anesthesia administration.

In this chapter, I have outlined the proper injection technique for performing anesthesia on the lower jaw, identifying the challenges that students face when learning this technique. I present theory and evidence on motor skills learning, a large category that includes experiential learning, guided discovery with just-in-time feedback, and issues related to self-efficacy. Each of the theories presented relates closely to the research questions listed in Table 1. Finally, the arguments are couched within previous research regarding learning with virtual, immersive, and augmented systems.

**Technique to Anesthetize the Bottom Jaw**

The challenges students face when trying to learn and become competent with anesthesia are better understood by knowing the specifics of performing such an injection. To anesthetize (numb) the bottom jaw, the deposition of anesthetic materials must be placed just behind and slightly higher than the mandibular (bottom jaw) foramen.
Table 1

<table>
<thead>
<tr>
<th>Research question</th>
<th>Instructional goals</th>
<th>Theoretical frameworks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In what ways do using virtual 3D objects allow for a greater understanding of</td>
<td>Conceptual competency of anatomy &amp; spatial relationships.</td>
<td>Motor skills acquisition (experiential learning, guided discovery, just-in-time feedback).</td>
</tr>
<tr>
<td>anatomical spatial and dimensional acuity?</td>
<td></td>
<td>Learning with VR</td>
</tr>
<tr>
<td>2. Will students develop better understandings regarding the application of</td>
<td>Demonstrated competency of anatomy &amp; spatial relationships.</td>
<td></td>
</tr>
<tr>
<td>anatomical and technical concepts through iteration?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Will students be able to demonstrate the proper technique and verbalize a</td>
<td>Investigation to the potential degree that mixed-reality has for the clinical</td>
<td>Motor skills acquisition (experiential learning, guided discovery, just-in-time feedback)</td>
</tr>
<tr>
<td>level of confidence for administering local anesthesia after using the mixed-</td>
<td>practice of anesthesia administration.</td>
<td>Self-efficacy</td>
</tr>
<tr>
<td>reality system?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(hole) on the inferior border of the jaw (Figure 1). The nerve that provides sensation to
the jaw passes through this foramen and must be anesthetized before it enters the dense
jawbone. If anesthetic is placed too far away from the foramen, it does not reach the
nerve before it passes through bone, and anesthesia does not occur. The mandibular
jawbone is too dense for the osmosis of anesthetic materials to have any impact on the
nerves (Malamed, 2004).
The first step in administering an injection in the lower jaw is to identify oral anatomical landmarks through palpation with the left hand (Figure 2, Table 2). The student feels for the internal oblique bony ridge. Once the ridge is identified with the forefinger or thumb bisecting the area between the top and bottom jaws, the pterygomandibular raphe can be visualized. The raphe is a muscle that goes from the bottom jaw between the last molar and the soft palate on the top jaw. A bottom jaw block injection must be given close to the foramen, in between the bone and the raphe. Visualizing the raphe is an essential landmark to administer a correct injection. The internal oblique bony ridge and the pterygomandibular raphe form an inverted triangle (Figures 3 and 4; Table 1), the middle of which is the target site for the insertion of the needle (Figure 3). Insertion of the needle must come at an angle that is almost perpendicular to the target site. This trajectory is necessary to get the needle as close as possible to the mandibular foramen on the inferior border of the mandible and to the
Figure 2. Palpation of bony ridge landmark (A). Insertion of needle in the middle of the inverted triangle (B). Label A is the internal oblique bony ridge & Label B is the pterygopalatine raphe. Both lines A and B form the sides of the inverted triangle (Haglund & Evers, 1988, p. 81).

Figure 3. Needle trajectory between bony ridge (A) and muscle of the raphe (B) to the deposition site of the mandibular foramen (C) (Haglund & Evers, 1988, p. 90).
Figure 4. Visual depiction of correct and incorrect needle angle. Angle on the same side of the mouth (A). The end of the needle would be horizontally too far away from the injection site to be effective. An angle from the opposite side of the mouth (B). The tip of the needle is in place for the deposition of anesthetic materials (Hanson & Rose, 2008).

Table 2

Steps for Administering an Anesthetizing Block Injection for the Bottom Jaw

| Local anesthetic technique | 1. Palpate for landmarks   |
|                          | a. Internal oblique ridge |
|                          | b. Pterygomandibular raphe |
|                          | c. Inverted triangle     |
|                          | 2. Insertion area: the middle of the inverted triangle. |
|                          | 3. Orientation of the needle bevel: at roughly a right angle to the nerve. |
|                          | 4. Target area: jaw nerve as it passes downward toward the mandibular foramen but before it enters into the foramen. |
nerve that passes through that foramen. In order to achieve this angle, the operator must make sure that the barrel of the syringe is over the premolars on the opposite side of the mouth (Figure 5). Once the needle has been inserted into the tissue, the operator must continue to advance the needle until it makes contact with the inferior border of the mandible. This contact is an indicator that the needle is in the correct position to achieve optimum anesthesia (Malamed, 2004).

With the consideration of the challenges to learning local anesthesia as just discussed, an educational intervention would need to offer the student a way to view the anatomy to get a perspective of the spatial and dimensional relationships, opportunity for guided discovery, and just-in-time feedback and time for self-controlled practice. In consideration of these identified needs, my instructional intervention, leveraging the benefits of a mixed-reality environment, includes a 3D image that can be manipulated to offer multiple views of the oral cavity and human cranium, the opportunity for guided discovery and just-in-time feedback with built in prompts for student learning, and the opportunity for iterative learning (Table 3).

Table 3

*Instructional Needs That Led to Instructional Intervention*

<table>
<thead>
<tr>
<th>Instructional need</th>
<th>Instructional intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain perspective on the anatomical spatial and dimensional relationships</td>
<td>3D image manipulative</td>
</tr>
<tr>
<td>Experiential learning guided discovery</td>
<td>Built in learner prompts</td>
</tr>
<tr>
<td>Self-controlled practice</td>
<td>Iterative learning</td>
</tr>
</tbody>
</table>
Learning Challenges Faced when Learning to Administer Local Anesthesia

- Understanding of Anatomical Spatial and Dimensional Relationships
- Understanding that Anatomical Form Dictates Recommended Technique
- Ability to think Critically when Faced with Atypical Anatomy

Instructional Needs

- A way to drive conceptual understanding of anatomical spatial and dimensional relationships.
- Opportunity for experiential learning and self-controlled practice.
- Opportunities for iterative learning to take place.

Devised Mixed-Reality Instructional Intervention Grounded in Stages of Motor Learning

3D Image Manipulative
Cognition

Prompts
Guided Discovery
Just-in-Time Feedback
Association

Iterative Learning
Automation

Instructional Goals

- Conceptual Competency of Anatomy and Spatial Relationships.
- Demonstrated Competency of Anatomy and Spatial Relationships.
- Investigation to the potential degree that mixed-reality has for the clinical practice of anesthesia administration.

Research Questions:

1. In what ways do using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity?
2. Will students develop better understandings regarding the application of anatomical and technical concepts through iteration.
3. Will students be able to demonstrate the proper technique and verbalize a level of confidence for administering local anesthesia after using the mixed-reality system.

Figure 5. Process of design.
Theoretical Grounding

Motor Skills Learning

Wulf, Shea, and Lewthwaite (2010) stated, “motor skills are an essential component of the expertise displayed by, and required of, individuals working in medicine or other health professions” (p. 76). The administration of local anesthesia is a complex process that involves the utilization and synthesis of knowledge, motor skills, and cognition. In learning to administer local anesthesia, students must first develop baseline knowledge of the anatomical structures of the head and neck as well as learn about local anesthetics. Then they learn the motor skills necessary to perform an injection.

How these skills are taught and practiced has changed over the past few years (Ringsted, 2009; Wulf et al., 2010). Educators need to provide a scenario where students can not only learn, but can also transfer that knowledge to a real-life clinical practice application (Ringsted, 2009). To enhance this type of experiential learning, most teaching curricula are based on constructivism, or “learning by doing” (Rehrig, Powers, & Jones, 2008, p. 223). Kolb (1984) stated that experiential learning creates knowledge, the “transformation of experience, an active process where a four-stage cycle translates experiences, through reflection, into concepts” (p. 21). Fitts and Posner (1967) developed a three-stage theory to explain motor skills acquisition (Aggarwal, Grantcharov, & Darzi, 2007). The three stages describe a “continuum” of “cognition” followed by “association” and finally “automation.” The learner is taught the task, practices the task, and finally performs the task “automatically” (Fitts & Posner, 1967, p.
Each cycle of tasks describes how motor learning is solidified, when the learner creates this “continuous feedback loop” (Aggarwal et al., 2007; Schmidt & Wrisberg, 2004, p. 97). Fitts and Posner’s (1967) three-stage theory is integral to the development of my instructional intervention.

As identified, my instructional intervention would need to include a 3D image that can be manipulated to offer multiple views of the oral cavity and human cranium, the opportunity for guided discovery and just-in-time feedback with built-in prompts, and the opportunity for iterative learning to take place. These instructional needs are aligned with Fitts and Posner’s (1967) stages of motor skills acquisition. The use of 3D manipulatives allows the student to gain a level of cognition to promote meta-cognition of anatomical structures and dimensional relationships. Further, the use of built-in learner prompts promotes the association of recommended technique and anatomical structure. Students are allowed to practice and build knowledge structures based on guided discovery, just-in-time feedback, and learner prompts. Last, automation of skills is supported with the opportunity for self-controlled practice, which allows the student to perform the task and drive iterative learning (Table 4).

Four factors that have been shown to enhance the learning of motor skills are observational practice, focus of attention, feedback, and self-controlled practice (Wulf et al., 2010). Observational practice involves the student observing the actions of others, either in the form of a video or live practice. Focus of attention specifies providing the learner with instructions that have an “external focus (directed at the movement effect) or an internal focus (directed at the performer’s body movements)”
Table 4

Aspects of Motor Skills Learning That Relate to Instructional Intervention

<table>
<thead>
<tr>
<th>Instructional need</th>
<th>Motor skills learning</th>
<th>Instructional intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain perspective on the anatomical spatial and dimensional relationships</td>
<td>Cognition Taught the task</td>
<td>3D image manipulative</td>
</tr>
<tr>
<td>Experiential learning guided discovery</td>
<td>Association Practices the task</td>
<td>Built-in learner prompts</td>
</tr>
<tr>
<td>Self-controlled practice</td>
<td>Automation Performs the task</td>
<td>Iterative learning</td>
</tr>
</tbody>
</table>

(p. 75). As well as having motivational properties that have an important influence on learning, feedback serves to provide the learner with important information about his or her progress. Finally, self-controlled practice allows the learner to control the learning situation and the pace of learning (Wulf et al., 2010).

**Guided discovery and just-in-time feedback.** Brown (1992) used the term “discovery learning” to intimate her vision of a Vygotsky-an approach to guiding the learning process and providing onsite and immediate feedback for students that participate in “hands-on” learning. As the architect for DBR, Brown described this instructional process as a way to help learners to identify the relationships between relevant materials. Guided discovery is one recommendation made to help students learn new information in context with other nonarbitrary relationships. Just-in-time feedback is feedback that is provided on-site to students just as they as performing a task. Just-in-time feedback will contextualize that learning for students and allow them to refine their skills (Schmidt & Lee, 2005). Part of the mixed-reality experience for this research will
include the scripted, guided discovery seen in Appendix A. The process of just-in-time feedback and guided discovery will help to ensure that a higher level of learning can take place using the working memory (Brown, 1992; Fitts & Posner, 1967; Schmidt & Lee, 2005; Wulf et al., 2010).

Guided discovery and just-in-time feedback is a source of valuable guidance in the development of my instructional designs and research. The first research question relates to conceptual competency for anatomical and spatial relationships. The resulting fruition of incorporating guided discovery with just-in-time feedback is the competency for anatomical conceptual relationships.

Traditional practices for learning techniques for administering anesthesia have utilized observational practice, focus of attention, feedback, and self-controlled practice. The last two factors have only limited success. First, students watch videotapes on specific injections being performed and try to replicate the process in practice. Instructors provide chairside advice and feedback on technique; however, they are limited in what they can see intraorally and in assisting the student in controlled practice. Because the student is working with a live patient, she does not have the freedom to make choices, identify mistakes, and retry again with the same patient (Shaffer et al., 2001). The student must wait until another opportunity comes along, which will come with another set of variables not present in the last situation (Malamed, 2004).

**Challenges Students Face**

I have identified through observation three challenges that students face when they start to learn the techniques for administering local anesthesia. First, they have a
difficult time transferring their knowledge of the anatomical structures of the head and neck to a real patient. Second, they have a hard time understanding that techniques for administration follow anatomical structural design. Third, they struggle with altering their technique per patient, as each patient demonstrates unique anatomical structure.

**First challenge.** When students look into the oral cavity of a real patient, they cannot see the underlying anatomical structures as seen in a text or on an anatomical model in a classroom setting. As a result, they pause and are unable to function without instructor intervention and direction. The first step is to palpate, or feel for, anatomical landmarks that will provide the students with a framework for operation. Then, they need to visualize the anatomical structures and progress tentatively with their injection.

As student motor skills are acquired, skill development takes place through repetitive practice (Schmidt & Lee, 2005). Motor learning is often inferred by observing relatively stable levels of the student’s motor performance (Schmidt & Wrisberg, 2004). There are two types of motor learning: implicit and explicit. Implicit learning occurs unconsciously with practice, while explicit learning is obvious and conscious (Abernethy, Poolton, Masters, & Patil, 2008). Demonstrations of explicit learning are more mechanical, awkward, and slow compared to the more smooth, fluid, and effortless-looking actions of “automatic” performance (Schmidt & Wrisberg, 2004, p. 13; Schmidt & Lee, 2005).

When a person “chokes” during a performance it is because they have shifted from implicit to explicit processes during a performance. Individuals under stress become more aware of their movements, thus relegating control of their movement to the
more “conscious” processes. There is a point, however, in motor skills acquisition where an individual moves to an autonomous stage where there is a greater emphasis on the motor aspects of the task and less emphasis on the cognitive aspects. This point, which occurs after much practice, requires a lower level of cognition to complete the task (Schmidt & Wrisberg, 2004).

Wulf et al. (2010) described “external” and “internal” intent on the learner’s focus of attention for the motor task at hand. The premise is that an external focus of motions necessary to complete the task promotes the utilization of unconscious or automatic processes, whereas an internal focus on one’s own movements results in a more conscious type of control that constrains the motor system and disrupts automatic control processes. An external focus facilitates automaticity in motor control and promotes movement efficiency. Traditional practice of repetitive skills performance can assist a learner in shifting their focus away from disruptive movements and into more fluid, unconscious motor performance. While it can be difficult to gain the experience necessary to build the motor skills for local anesthesia, a mixed-reality environment can offer the opportunity for repetitive practice to accelerate this process.

**Second challenge.** Students do not always understand the recommended techniques for certain injections. This lack of understanding is due to the fact that the overlying tissues present in a real patient’s mouth obstruct the student’s views of the underlying anatomical features. For example, when a student first attempts to complete a block injection for the bottom teeth, she does so from the side of the jaw that ultimately needs to be numb. However, as Figure 5 illustrates, to place the needle as close as
possible to the intended anesthetic deposition site, the student would have to be inserting at an angle from the other side of the jaw.

Spatial accuracy is more important than large motor skills, speed, or strength. A student needs to rely on her knowledge of head and neck anatomy and needs to be receptive to proprioceptive and exteroceptive feedback (Schmidt & Wrisberg, 2004; Schmidt & Lee, 2005). As a needle advances through tissue, there are various details that can be detected with the sensorimotor feedback (proprioception) such as tight tissue, penetration of muscle, or even bony contact. All of this information is crucial for interpretation because it gives the student an idea of exactly where the needle is. During this process it is important to watch for patient response, or exteroceptive feedback, as that can provide valuable information to the operator as well (Malamed, 2004).

When performing a task, the process of interpreting input and then making appropriate motor decisions based on that input is referred to as a “closed loop” skill. Each decision and each movement represents an individual process that, when completed, “closes the case” on that part of the task. During a “closed loop” process, students rely heavily on cognition and problem-based decision making. In the case of an “open loop” skill, the student has reached a level of expertise whereby the decision-making process is not conscious. So, the “case is open” for the duration of the skill because the lengthy decision making seen in “closed loop” skills does not occur. “Specific psychomotor skills are required, which cannot easily be acquired by extrapolation from open surgery.” (Schijven & Jakimowicz, 2003; Schmidt & Wrisberg, 2004; Schmidt & Lee, 2005) The open-looped concept relates to the need for repetitive practice (automation), already
discussed, and provides rationale once again for the need of a mixed-reality environment that would allow for the development of motor skills before live practice.

Students must develop visual acuity for static and dynamic situations in order to perform local anesthetic. In addition, size constancy and depth perception are important (Schmidt & Wrisberg, 2004). This leads us to the next challenge of visualizing correct procedure as it relates to anatomical structure.

**Third challenge.** The final challenge for the students is the cognitive process presented when a patient does not exhibit “normal” anatomical landmarks. For example, when performing an injection for the top back teeth, a student would look for the back portion of the second molar as a landmark. If a patient presents without a second molar, it may confuse the student. At times a student will forget to insert just behind that particular molar and not just the last tooth in the jaw, in which case the needle will hit bone and the injection will be ineffective. When bone is hit, the student needs to think through the rationale of the original recommended technique and remember that the deposition site is behind the top jaw and zygomatic bone. Palpating the zygoma will help the student recognize the correct insertion site and continue with the injection (Malamed, 2004).

The oral cavity is an unpredictable environment because it is attached to a human, which is a physiologic entity that is incredibly unpredictable. When performing injections, students must learn to make decisions and adapt to each unique environment. Patient response, unique anatomical structures, and the patient’s tongue, saliva, and level of bleeding differ with each patient. Skills that are performed in unpredictable
environments like the human mouth are classified as “open” skills (not to be confused with “open loop” control). An open skill requires students to adapt their movements in response to dynamic properties of the environment. Skills that are performed in a predictable or stationary environment are said to be “closed” skills (not to be confused with “closed loop” control). A closed skill allows the student to plan her movements in advance. In this case, the words “open” or “closed” simply refer to the environment where the activity is taking place (Schmidt & Wrisberg, 2004). LAMRS offers students to practice in a controlled environment that eliminates unpredictability so that closed-loop skills can be practiced.

When learning a new skill, students appear more stiff, inaccurate, inconsistent, slow, halting, indecisive, rigid, and inefficient with many errors. With practice they develop skills that appear more relaxed, accurate, consistent, fluid, confident, decisive, adaptable, and efficient, with fewer errors. In the later stages of learning, students will appear more automatic, accurate, consistent, fluid, confident, certain, adaptable, efficient and will recognize errors (Table 5) (Schmidt & Wrisberg, 2004). Again, a mixed-reality environment provides the opportunity for students to gain fluid and efficient motor skills so that live practice can be more effective and productive.

Positive feedback has a facilitatory effect on learning (Wulf et al., 2010). Novice clinicians lack disciplinary and pedagogical expertise along with concomitant confidence in procedures for local anesthesia (Bencze, 2010). Therefore, positive feedback and experiential learning are critical for the development of self-efficacy in learning and practice of motor skills (Bencze, 2010; Schijven & Jakimowicz, 2003; Wulf et al.,
Table 5

*Stages of Motor Learning and Associated Motor Performance Characteristics*

<table>
<thead>
<tr>
<th>Early stages of learning</th>
<th>Later stages of learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive (trial and error),</td>
<td>Autonomous (free and easy)</td>
</tr>
<tr>
<td>associative (honing in)</td>
<td></td>
</tr>
<tr>
<td>Verbal motor (more talk)</td>
<td>Motor (more action)</td>
</tr>
<tr>
<td>Getting the idea of the movement</td>
<td>Fixation/diversification (closed or open skill)</td>
</tr>
<tr>
<td>Coordination (acquire the pattern)</td>
<td>Control (adapt the pattern as needed)</td>
</tr>
</tbody>
</table>


2010).

**Issues of Self-Efficacy**

Issues of self-efficacy relate to my project, as repetitive practice can impact increased level of confidence for the performance of correct clinical technique for local anesthesia. Bandura (1982) stated that while a student may know perfectly well how to complete a task, they may not behave optimally. This is because “self-referent thought also mediates the relationship between knowledge and action” (Bandura, 1982, p. 122). Bandura defined perceived self-efficacy as a “concern with judgments of how well one can execute courses of action required to deal with prospective situations” (p. 122). A person’s ability to believe that they can complete a task involves cognitive, social, and behavioral skills (Bandura, 1982; Hoffman & Schraw, 2009, p. 3).

Wei (2008) stated self-efficacy is “one’s efficacy to exercise control over one’s
functioning and events that affect one’s life” (p. 649). Successful students in academia hold a high level of personal motivation, have a behavior for better learning strategies, and respond to environmental demand more appropriately (Wang & Wu, 2008). Students who believe they have the capability to execute actions that will bring about a desirable result are more successful academically.

Self-efficacy is a component of social cognitive theory. According to social cognitive theory, “self-efficacy is the foundation of human motivation and accomplishments because it affects each of the basic processes of personal change” (Peng, 2008, p. 649). A person will not make the effort to change if he or she does not believe there is a chance of success. Success depends on the ability to visualize performance, perform, and recover from failures (Bandura, 1982). Self-efficacy beliefs can influence human behavior and be linked to self-confidence (Papastergiou, 2009). Further, empirical evidence suggests that self-efficacy impacts a person’s affective state: attitudes, motivation, and perseverance. Also, poor self-efficacy makes students vulnerable to stress and anxiety (Papastergiou, 2009; Wulf et al., 2010).

Enactive and observational experiences are two of the most common sources of self-efficacy. Enactive experience involves direct learning where students participate in an activity within a real physical environment, examining the pattern of outcomes they have directly experienced and generating conceptions and rules of behavior (Peng, 2008; Wei, 2008). Observational experience, on the other hand, is the development of self-efficacy through the vicarious observations of the behaviors and success of others in complex environments. Enactive experience is more effective than observational
experience in increasing self-efficacy (Peng, 2008).

Wang and Wu (2008) concluded that feedback was a powerful force for developing self-efficacy and most effective if done immediately by another person. The speed with which experiences, consequences, feedback, and conceptual change are processed depends on the working memory capacity and cognitive load of the learner. Working memory capacity depends on the problem-solving skills of the learner; hence, students with high self-efficacy have a higher level of motivation, better learning strategies, and more successful interactions with their environment (Bandura, 1982). The mixed-reality system for this research was created to allow students to gain enactive experience in a virtual environment. Virtual enactive experience allows for confidence to build and skills to develop (Peng, 2008).

The technical skills in medicine and dentistry have been commonly taught using the apprenticeship model (Schlosser et al., 2007). Due to a variety of constraints that include both ethical and economical realities, apprenticeship training has become problematic (Schlosser et al., 2007; Tsang et al., 2008; Wulf et al., 2010). Therefore, training outside the dental operatory offers a structured educational opportunity with stress modulation, which reduces the trainees stress in the clinical environment (Schlosser et al., 2007; Tsang et al., 2008). Simulators in the form of box trainers and virtual reality systems have been created for training outside of the dental operatory (Schijven & Jakimowicz, 2003). Virtual simulation offers an alternative in medical and dental training that offers a learning environment that is realistic, educational, and interactive (Tsang et al., 2008).
Learning, Artificial Environments, and Augmented Reality

The trial for educators is to combine educational psychology with curriculum and instructional methods that leverage the natural abilities of the learner. Research on education in immersive environments has shown that advanced visualization technologies often can impact the cognitive strategies and abilities of the learner (Bimber & Raskar, 2005; Winn & Windschitl, 2001). Further, learning in artificial environments is successful because students can cognitively construct knowledge for themselves as they interact with the environment and observe the consequences of their actions (Bowman, Kruijff, LaViola, & Poupyrev, 2005; Burdea & Coiffet, 2003; Shelton & Hedley, 2004).

Virtual environments allow for a first person, complex spatial experience that allows considerable freedom to choose experiences and, especially, make mistakes. The identification of errors and the opportunity to correct them are advantageous for building learning strategies in complex learning environments (Schijven & Jakimowicz, 2003; Waterworth & Waterworth, 2001; Winn & Windschitl, 2001). Barab, Hay, Barnett, and Squire (2001) stated that an environment that supports that development of rich conceptual understandings is a participatory learning environment (PLE) in which students are allowed to ground their knowledge via participation. In a PLE environment the curriculum is learner centered, hence shifting away from the concept of the learner as a person to be changed.

Depending on the kinds of activity in which they are engaged, students can develop rich conceptual understandings using an interface that allows for the manipulation of 3D objects in virtual space. Because the student has control over what
objects he or she sees and when they are seen, the virtual environment offers a certain level of autonomy and virtual presence (a feeling of reality) (Bimber & Raskar, 2005; Bowman et al., 2005; Burdea & Coiffet, 2003). “Learning while doing” embodies theoretical concepts that humans acquire new knowledge by physical manipulation of objects and/or concepts, which in turn allows the learner to physically see causal relationships between action and result (Aldrich, 2004, 2005; Engestrom, 2001; Leontiev, 2005; Shelton & Hedley, 2004).

Artificial environments should meet three criteria: high levels of presence, interactivity, and autonomy (Bowman et al., 2005; Burdea & Coiffet, 2003; Winn & Windschitl, 2001). In conventional instructional environments, a delay exists between student actions and environmental reactions, making the give-and-take that must exist for adaptation to occur disjointed and decontextualized (Behrend & Rosenthal, 2007; Cates et al., 2007). The purpose of mixed reality is to overcome decontextualization difficulties while at the same time maintaining the ability to teach abstractions directly through realistic experiences in the virtual world, allowing students to construct their own understandings and drive conceptual change (Shaffer et al., 2001; Sandoval & Bell, 2004). This information was relevant due to the instruction about the pedagogical elements that go into designing a virtual system for learning.

**Virtual approaches in practice.** The manipulation of 3D virtual objects and related learning aspects has been previously researched (Barab et al., 2001; Shelton, in press; Shelton & Hedley, 2004). Shelton and Hedley explored knowledge acquisition with the construction of knowledge using advanced spatial visualization tools –
specifically augmented reality interfaces. Shelton and Hedley reported on research they found where users manipulated a hand-held card that served as a platform on which to project the 3D objects seen via a liquid crystal head mounted display (HMD). Shelton (in press) conducted research with a purpose to teach earth-sun relationships via a first-person perspective manipulative where the students had control over what they wanted to see and how they wanted to see it. In addition, the students were allowed to make changes in variables and check their solution. Shelton’s findings revealed that most students participated in the manipulation of the virtual objects and used visual spatial cues during their learning process. He further postulated that people learn relative spatial relationships by using perceived referents during physical manipulation of virtual objects. Shelton’s (in press) findings support my hypothesis that students will learn anatomical spatial relationships and techniques for anesthesia using augmented reality.

Mangan’s (2000) research provided students with a noninvasive, immersive environment for the purpose of practicing and building skills for surgery via the MIST system. Her findings supported that most surgeons found helpful the opportunity to practice in a realistic, nonstressful environment that allowed them the latitude for failure. Students learned faster and were more ready for actual live patient surgeries. Mangan’s findings suggested that an augmented reality interface will decrease the time needed for learning certain skills and decrease the cognitive load while learning skills like performing local anesthesia. Hence, the students involved in my research should function with a higher level of confidence and lower level of error with an actual patient.

Research conducted by Quinn, Keogh, McDonald, and Hussey (2003) is relevant
because their evidence supported that students did learn better in an artificial environment. Their environment included the use of a mannequin patient referred to as a DentSim with an intraoral camera that provided a 2D view of involved procedures. On a chairside visual display students could see a magnified view their hands and their work as they performed on the DentSim. Clinical instructors could view student practice on a computer screen in a central location. If the student’s technique was flawed, the instructor could call give immediate feedback (via a speaker) on the attempted clinical skill. Research findings support that students did perform better in a live patient situation after having had the chance for simulation. However, the use of the DentSims was problematic; students could not alter their view of the oral cavity, and the DentSim tissue structure would wear out periodically, reducing reusability over time.

Mixed-reality environments offer affordances that cannot be achieved with other environments, specifically, the ability to investigate, 360 degrees, a 3D object and cement relationships of structures not only in one plane but in multiple planes (i.e., bone and the tissues that cover bone). Immersive simulation experiences allow students to make movements and directly see the impact of those motions, allowing them to go through a process of “cause and effect” and make changes in their engagement strategies. In Table 6, I have included details of where mixed-reality enhanced my instructional intervention.

**Summary**

In this chapter, I provided the reader with a clear idea of what students face when learning the technique for administering injections. I also provided learning theory behind the recommended strategies that underlie my research. My purpose was for students to
Table 6

*Instructional Intervention Related to Learning with VR Systems*

<table>
<thead>
<tr>
<th>Instructional need</th>
<th>Motor skills learning</th>
<th>Instructional intervention</th>
<th>Learning with VR systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain perspective on the anatomical spatial and dimensional relationships</td>
<td>Cognition</td>
<td>3D image manipulative</td>
<td>Enhance cognition and learning</td>
</tr>
<tr>
<td>Experiential learning guided discovery</td>
<td>Association</td>
<td>Built-in learner prompts</td>
<td>Directly see impact of actions</td>
</tr>
<tr>
<td>Self-controlled practice</td>
<td>Automation</td>
<td>Iterative learning</td>
<td>Make mistakes and change strategies</td>
</tr>
</tbody>
</table>

gain cognition for anatomical spatial and dimensional conceptual relationships and be able to demonstrate these understandings in a clinical setting. The acquisition of motor skills not only involves the physical movements necessary to complete a task but also the ability to think critically and understand concepts learned. It is for this reason that I included motor skills learning in my theoretical grounding because theory on this subject outlines strategies to enhance motor skill development as well as to promote critical thinking (i.e., guided discovery and just-in-time feedback). A big part of motor skills performance has to do with a student’s confidence in her own capabilities to complete a task. Enactive experience, or first-person practice, is the best way to gain self-efficacy and confidence. Also, in this chapter, I discussed learning with artificial environments and augmented reality. The use of artificial environments like mixed-reality systems allow for a first-person, complex spatial experience that allows the students to choose
their experiences, make mistakes and correct their technique. Mixed-reality technology allows for repetitive practice, motor skills development, iterative and enactive learning, and the development of self-efficacy.

Specifically, I presented the challenges that students face when learning techniques to administer local anesthesia. These challenges include the need to understand the oral anatomy and the cranial anatomy deep to the oral tissues. An understanding of this anatomy provides cognitive support to conceptualizing that anatomical form dictates recommended technique. Once a student demonstrates the ability for metacognition, they can extrapolate and think critically when presented with atypical anatomy. Thinking through the challenges led to the identification of the instructional needs that were addressed. I would need a system that drove a better understanding of anatomical spatial and dimensional relationships, provided opportunity for experiential learning and self-controlled practice, and could provide for iterative learning to take place. The result was a mixed-reality instructional intervention that was grounded in the three stages of motor learning: cognition, association, and automation. The use of 3D manipulatives allowed the student to gain a level of cognition to promote metacognition of anatomical structures and dimensional relationships. Further, the use of built-in learner prompts promoted the association of recommended technique and anatomical structure. Students were allowed to practice and build knowledge structures based on guided discovery, just-in-time feedback, and learner prompts. Last, automation of skills is supported with the opportunity for self-controlled practice, which allows the student to perform the task and drive iterative learning. The created instructional
intervention supported the research goals created for this research and led to the
development of the research questions that I wanted to investigate during my research
(Figure 5).
CHAPTER III
THREE PHASE DESIGN AND DEVELOPMENT WITH EDUCATIONAL INTERVENTION PROCEDURES

The vision at the beginning of this research was to provide the student with a simulated experience that would allow them to synthesize learned concepts about local anesthesia with taught techniques for performing an injection. In the past, students have performed well in a classroom environment, indicating a clear understanding of material relating to cranial anatomy, injection technique, and local anesthetic materials. However, in a clinical setting, students exhibited a cognitive disconnect when they held a syringe in their hands. The fear of hurting someone while they attempted to conceptualize and cement information learned through hands-on learning immobilized students. My goal was to provide a simulation that was realistic enough to provide the “hands on” feel but without the fear of injuring someone. With a simulation, there are additional benefits on top of fear reduction: the benefit of built-in learner prompts, iterative learning with just-in-time feedback, and customized manipulation of the 3D image.

Student Learning Goals

For future practice, students must understand that anatomical form dictates clinical technique for every injection. Understanding the relationship between form and technique is a crucial component to critically thinking through an injection procedure. The student has to be able to consider their ultimate goal: to deposit anesthetic materials as close as possible to the nerve trunk that provides innervations to the area they want
numb. With this in mind, the student should be able to strategize the route necessary for
the needle, from penetration to deposition site, to gain access to this area. Every patient
presents with different oral anatomy but most everyone will exhibit the same bony
structure. Therefore, the student must be able to correlate what they can see clinically in
the oral cavity with those anatomical structures under the tissue. For example, the
clinical landmark for performing a block injection for the top back teeth is the back part
of the second molar. The rationale for the second molar is that if a needle penetrates the
tissue at this site, it is most likely far enough back in the mouth to miss the bone (lower
wing of the sphenoid) that would prevent access to the nerve. If a patient does not have a
second molar, the student still needs to understand that the purpose of the technique is to
miss contact with that bone. If the student fails to go back far enough in the mouth, they
will meet with bony contact and be unsuccessful in their injection attempt.
Unfortunately, the most common response for a student when faced with a patient
presenting with atypical anatomy is to base her technique off of what she can see
clinically instead of the spatial and dimensional relationship of the anatomical structures
that cannot be seen.

The purpose of my research was to develop a mixed-reality system to identify
how 3D objects allowed for a greater understanding of spatial and dimensional acuity, if
students would develop better understandings regarding anatomical form and
recommended technique, and if students would be able to demonstrate proper technique
using a virtual system and develop a level of confidence for their performance. The use
of LAMRS, a mixed-reality environment, would assist the students in their perceptions
and understandings of anatomical spatial relationships that are critical for learning the
techniques associated with administering local anesthesia and for the completion of other
dental procedures that require similar skills.

**DBR Methodology**

Brown (1992), an educational design scientist, sought to create innovative
educational environments where she could also conduct experimental studies of these innovations. Brown’s efforts, along with those of Collins (1992), worked toward a
theoretical model of learning and instruction rooted in a firm empirical base. Design experiments were developed to carry out formative research as a way to test and refine educational designs based on principles derived from prior research (Collins, Joseph, & Bielaczyc, 2004). These types of experiments were referred to as DBR, where the researcher is engaged in theoretically framed empirical research on related educational phenomena. This “theory work” is a defining feature of DBR (Bell, 2004). With DBR, the focus is on the efficacy of an instructional intervention or software utilized in authentic educational contexts without attachment to or advancement of theoretical constructs (Bell, 2004). Barab and Squire (2004) stated that “validation of a particular design framework is not simply intended to show the value of a particular curriculum but results in the advancement of a particular set of theoretical constructs” (p. 9).

In addition, for a research project to be considered DBR, it must exhibit the following five characteristics:

- the central goals of designing an environment and developing theories of learning are intertwined;
development and research take place through continuous cycles of design, enactment, analysis, and redesign;

research on design must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers;

research must account for how designs function in authentic settings and focusing on interactions that refine our understandings of the learning issues involved;

methods here should document and connect the processes of enactment and outcomes of interest. (The Design-Based Research Collective, 2003, p. 5)

I will specify how my project has met these design characteristics.

Flexibility is crucial in the creation and testing of a new learning tool (Kong, 2008). DBR is appealing because it offers a systematic but flexible methodology aimed to improve educational practices through iterative practice (Bell, 2004). With DBR, one can pragmatically employ qualitative or quantitative research methods that are congruent with the research questions. Alignment of research questions with procedures allows the researcher to adjust and fine-tune data collection methods in response to emerging questions and research goals (MacDonald, 2008). Therefore, DBR is a descriptive process rather than prescriptive like traditional empirical practice. Results are presented with a description of the research process and outcomes as well as on the theoretical impact. Further, the importance of the work is described as having experience-near significance, in the advancement of researching instructional intervention, and
experience-distant relevance, in the advancement of relevant theory (Barab & Squire, 2004).

Strobel, Jonassen, and Ionas (2008) conducted DBR on the evolution of a collaborative authoring system for nonlinear hypertext. They performed three cycles of design research activities over a three-year period. Insights gained from the continuous cycle of design, enactment, analysis, and redesign allowed them to articulate a theory of nonlinear hypertext use in college classrooms. The resultant theories were shareable and had implications for practitioners and designers who want to focus on design in authentic settings.

Sharma and McShane (2008) utilized DBR of understanding and describing discipline-based scholarship of teaching in higher education. Work was done with a focus on practitioner action research and heavily involved the input of the educators that were part of the project. Sharma and McShane felt that a collaborative relationship between the designer, researcher, and participants was an integral part of the cyclical process of DBR. In the presentation of research outcomes, tables are presented with specifics for each phase of their research. Using Sharma and McShane’s example, I have utilized this same concept to present the phases of my research.

Finally, Joseph (2004) uncovered the interplay between DBR and real-world context. She gives examples of experiences she had with her project, “the passion curriculum.” Three key functions in DBR were highlighted. First, design considerations provide a focus for developing research questions. Second, design development can take place on several fronts simultaneously, with some design solutions for the system or
learning tool and some for the research and analysis process. Third, emergent theories inform both the design of interventions and the development of lenses for investigation. I found Joseph’s research to be helpful and applicable for this study. In her methodology she employed the use of audiotapes the documented learner behavior during research. These tapes were evaluated and coded for episodes of activity that helped to develop a research apparatus for future phases of research. I have employed a similar method of qualitative analysis of learner behaviors and have used those outcomes to build a framework for analysis on my next phase of research.

My research was grounded in the philosophy of DBR to create an innovative educational environment that can be researched and developed simultaneously. Since 2005 to present, work has been conducted to create a mixed-reality system to teach techniques for local anesthesia to dental hygiene students. This system has been refined to include a mix of the user’s real world combined with a virtual world referred to as LAMRS. Throughout the research, a DBR approach was employed to evaluate learning outcomes and subsequent system design changes. DBR consists of short cycles of technology design, in situ application, evaluation, and formulations of redesign (Barab & Squire, 2004; Joseph, 2004). Therefore, DBR is an iterative process: development takes place through “continuous cycle of design, enactment, analysis and redesign” (Sharma & McShane, 2008, p. 259). The LAMRS project has been through three cycles of design, enactment, analysis, and redesign (Figure 5). Those theories that frame my research are motor skills learning, learning with VR, and self-efficacy, as specified in Chapter II and Table 1.
Design and Development Iterations for LAMRS

A critical goal for my virtual system was to emphasize anatomical spatial and dimensional relationships, to create the allowance for customizable manipulation of the 3D image, and to provide learner prompts for the identification and visualization of the inverted triangle. I knew which learning aspects of local anesthesia I wanted to enhance with the use of VR; however, at the beginning of this quest, I had no experience with VR, simulations, or artificial environments. Therefore, I started out with two simple goals: to become more familiar with VR technologies and to create and build an affordable system that would allow for the learning that I had envisioned. It was during this initial phase of research that I realized that I would need to be flexible with the design and development of my system, as I was constantly learning and changing design aspects based on the process and new knowledge gained. So, at the analysis stage of Phase I research, I made plans for redevelopment and another research phase so that I could improve my system and get closer to the immersive experience that I had originally intended (Figure 6).

The result was Phase I, II, and III of research as depicted in Figure 6 and outlined in Figure 7. Each phase had a specific budget, research goals/questions, and technological design considerations that were created based on the preceding phase outcomes. Between Phases II and III, some design aspects were kept and others were improved upon while the research questions remained consistent.

My intent in Chapters III, IV, and V is to provide the reader with an understanding of the progressive hardware and software improvements in LAMRS, from Phase I to III, and describe the student experience at each phase. The presentation of all
three sequential phases of research includes questions, methodology, results, and discussion. Chapter VII includes the outcomes of all phases.

<table>
<thead>
<tr>
<th>2005</th>
<th>2007</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I:</td>
<td>Phase II:</td>
<td>Phase III:</td>
</tr>
<tr>
<td>Exploratory</td>
<td>Proof of concept</td>
<td>Refinement</td>
</tr>
</tbody>
</table>

*Figure 6. Iterations of LAMRS using DBR.*

**Summary**

In this chapter, I have described DBR and briefly outlined the design and development process of LAMRS using this process. I have outlined those details that I wanted the student to learn and explained how each iteration of design got me one step closer to achieving my educational goals. Phase I design involved the use of rudimentary rendering system using a low resolution, nonmanipulative, 3D image. Phase II design changes included the use of human magnetic trackers and a sophisticated 3D image that could be manipulated. Phase III included the refinement of the system calibration, improved hardware and the inclusion of a data glove to reify the left hand with the system (Figure 7).
Figure 7. Improvements to LAMRS driven by DBR.
CHAPTER IV

PHASE I: EXPLORATORY

An overview was provided of the design and development of LAMRS in the last chapter using DBR. The purpose of this chapter is to outline the research methodologies employed during Phase I, the exploratory phase of my research. My research goals at this stage were to: (a) become familiar with VR through Internet research and a review of literature, (b) investigate what types of learning takes place with VR, and (c) to create a VR system aligned with my instructional intervention (Figure 8). I followed an informal process of investigation and in the analysis of the application of the VR system that I created. In the Spring of 2005, I worked with three students to investigate VR using the $2,000 we had at our disposal.

Phase I: Exploratory - Initial Design and Development

Three undergraduate research students agreed to work with me starting in the spring going into the next year. We worked as a small team and did not have any outside professional help at this time. We had a development budget of $2,000. With this money we purchased our most expensive item, the iGlasses PC/SVGA. We knew that we would need a mobile visual display for the user to see our 3D image from an immersive, first-person perspective. The iGlasses were the cheapest head mounted display (HMD) that we could get away with at the time. Other purchased hardware included a webcam. We already had a Dell desktop computer that we used for the virtual engine. We researched software on the Internet to create our 3D image and discovered Daz studio. The software
Figure 8. Phase I: Exploratory - design and development.
was free and we could purchase kits for different models with different characteristics. It was relatively inexpensive to purchase a Daz Man kit and create a 3D image of the human cranium. Other software included ARToolKit, freely available software on the Internet that employs a pattern recognition rendering system to display the 3D image in the HMD. At this stage, our tracking system was the pattern recognition ARToolKit software. We did not have the funding to integrate haptics, navigation, and integration software at this time.

As mentioned, I was a novice at VR technologies and so were my research students. We had to investigate absolutely everything from the definition of a “vrml” to what was meant when we got a message that we were missing a “msvcirtd.dll” file. We kept a blog throughout Phase I to chronicle our process and to provide advice for others that may simulate our methods in the future. I have included the first two posts of the blog so that the reader has an idea of those concepts we were struggling with and learning at this stage of development.

May 7, 2005

We started working on our Augmented reality project for Weber State Dental Hygiene students. Our purpose is to use augmented reality to teach and learn local anesthetic. We started off by reviewing our calendar for the summer and then researching and downloading those programs and documents needed for our project.

- We downloaded ARToolKit on our home computers
- We practiced rendering images using ARToolKit and a webcam
- We researched the best head mounted display available in our price range
- We purchased personal webcams for home instant message conferences
- We subscribed to the ARToolKit mailing list to explore others questions on augmented reality
- We read and followed the tutorial on ARToolKit
May 9, 2005

Today we started familiarizing our group with computer software programming and Microsoft visual studios. We purchased our Head mounted display (i-glasses) and we started to use the image cards we printed from the Washington HITLab website to render images with our webcam. We reviewed the archive of the ARToolKit mailing list to see if any other groups or persons had asked the same questions we had. Our questions were:

- How do we render VRML (virtual reality modeling language) images?
- What is the best HMD to use?
  - What does msvcirtd.dll mean and if it is a file how do we find it?
    At first we thought it was part of a firewall but we ran an antispyware program and it still gave us the msvcirtd.dll missing file error.
    msvcirtd.dll is a file library.
    msvcirtd.dll and msvertd.dll are both available in ARToolKit 2.65 (not vrml) and we copied and pasted those files from 2.65 to ARToolKit direct show 2.52 vrml and the missing file alert did not come up and we were able to render and image on our home computers.

We looked at i-glasses which has a resolution of 640x480 which is pretty poor but usable. We also looked at the olympus(eyetrek)FMD 700 but it did not have see through mode. We looked at cy-visor at www.personaldisplay.com but those did not have see through mode either. We researched glasstron by sony but those were out of our price range.

We are not computer programmers but we need to know some things about coding in order to get the image that we need. We are and will be continuing to get familiar with coding by doing the examples on the ARToolKit manual.

**Phase 1: Exploratory - Process of Investigation**

My process of investigation included the study of VR technologies using the Internet, and books published on VR concepts and components. Once my students and I
were aware of how to get started, we set out to build a VR application that fit into our budget (Figure 9). The analysis involved an alignment with the virtual system and my instructional intervention. My success was determined by my ability to create a VR system and by my ability to write a proposal for funding cogent enough to be awarded funding. My evaluation of the VR system was predicated on its ability to provide for a manipulative 3D image, the opportunity for experiential learning and just-in-time feedback, and self-controlled practice and iterative learning.

**VR Technologies Research Process**

To become familiar with VR, three senior dental hygiene students and I spent six months researching the use of and applications for VR technologies. We researched articles that discussed VR applications with specific learning goals that mentioned technological aspects. We purchased support textbooks that helped us understand the articles we had amassed. One particularly useful resource was *3D User Interfaces*

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*Figure 9. Phase I: Exploratory - process of investigation.*
(Bowman et al., 2005). This book provided VR taxonomy as well as simple descriptions of hardware and software options based on individual development considerations.

Next, we browsed the Internet for reputable websites that offered excellent information on VR technology and included listservs that novices could join. Some websites we frequented included the Human Interface Technologies Lab (HITLab) at the University of Washington, the New Media Consortium’s (NMC) Virtual Worlds website, and the Georgia Tech website on Graphics, Visualization and Usability. Membership on a quality listserv such as the HITLab and/or Georgia Tech proved helpful because observing the dialogue that takes place on these listservs exposed us to relevant jargon, complex technical concerns, and collaborative problem solving that helped us later in our own research. In addition, we looked for open sourced (freely available) VR content on the Internet. A lot of VR toolkits and other valuable resources have been open sourced. For Phase I we used the open sourced toolkit called, ARToolKit, which we downloaded off the HITLab’s website.

**Creation of VR System and Research Procedures**

In learning more about VR systems, my students and I gathered information related to the decision-making and purchase of VR hardware and software. Then we utilized my newly acquired knowledge to create a VR application for teaching. With this application, we started out with the components listed in Figure 36. Using ARToolKit, we created a rudimentary VR application for viewing a 3D model (or image) of the human cranium. The 3D image was created with the use of Daz Studios software. Daz Studio was freely available on the Internet and not highly sophisticated. The image
quality was poor and not easily altered. ARToolKit used a pattern recognition system to render virtual images. This meant that predetermined patterns were printed out and used with a webcam. When the webcam has a particular pattern in its view, it cues the computer to render the 3D image it is programmed to display. With this rendering system, it is crucial that the camera view of the image is uninterrupted. An interruption of the view will cause the 3D image to disappear.

**Phase I: Exploratory – Results**

Research results indicated that while my knowledge base on VR technologies increased, I was not able to create and operate a VR system for learning during this exploratory phase. The hardware and software that I acquired included ARToolKit, iGlasses, a Daz Studio image, and a webcam. My students were not able to interact with the 3D image that I had created. The image was a low-fidelity, low-quality image and did not provide the in-depth analysis of anatomy that I had hoped. Also, the image could not be manipulated; in fact, when my students tried to interact with it, it would disappear. Therefore, self-controlled practice and iterative learning were not supported.

**VR Research**

Most of the theoretical information that I learned formed the basis for my literature for this dissertation. Also, I learned a lot about instructional strategies and the design process. At first, I designed my virtual environment based on what was cheap and readily available on the Internet. I realized that the instructional objective should be considered first, and then what type of virtual reality environment and activity would best
fit the need of that objective. How do I create an environment to teach what I am trying to teach? My conundrum lay in the struggle between the ideal learning environment and the pragmatic solution based on available resources. Should I first consider technological decisions and the accompanying constraints that follow those decisions? Or should I follow a traditional approach to create education based in instructional design and learning objectives? Being a novice, my investigation of VR was a challenge. I learned through experience and included the four basic steps that help alleviate the stress of the design process (Table 7).

Knowing this information would have assisted me in making important decisions at the beginning of the design process. For example, with the first step, *articulate expectations*, I wanted my students to use both hands (bimanual) to explore (palpate) the anatomical model viewed in the virtual world. This bimanual palpation required a higher level of programming, funding, and hardware than was initially planned for. The original plan only allowed for one hand to function virtually. If I had clearly articulated my expectations at the beginning, I might have understood that the system I was building did not allow for what I wanted.

Early on I experienced frustration because I lacked an understanding of the definition of some of the following terms that are the traditional components that constitute a VR system (Burdea & Coiffet, 2003; Hanson & Shelton, 2008). *Input*: the data sent to the computer for analysis based on the user’s interactions with the virtual world. *Output*: the computer rendering of the analyzed input that the user senses as a result of their interactions. *Software and databases*: allow for the modeling of the 3D
Table 7

Basic Steps in the Design Process

<table>
<thead>
<tr>
<th>Design process steps</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate expectations</td>
<td>• State how the conceived of lesson plan will be enhanced with the utilization of VR technologies.</td>
</tr>
<tr>
<td></td>
<td>• State specifically what it is expected that the user will see, hear and/or feel in the virtual world.</td>
</tr>
<tr>
<td>Become familiar with VR</td>
<td>• Research articles and textbooks.</td>
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<td></td>
<td>• Browse the Internet for valuable information.</td>
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<td></td>
<td>• Join Listservs.</td>
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<td></td>
<td>• Investigate open sourced VR toolkits and applications.</td>
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<td></td>
<td>• Start networking and making professional contacts.</td>
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<td></td>
<td>• Contact colleagues.</td>
</tr>
<tr>
<td></td>
<td>• Contact leaders in the VR industry and the authors of articles of interest.</td>
</tr>
<tr>
<td>Evaluate design considerations</td>
<td>• Design of the virtual world.</td>
</tr>
<tr>
<td></td>
<td>• Level of desired immersion.</td>
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<tr>
<td></td>
<td>• Modes of sensory feedback.</td>
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<tr>
<td></td>
<td>• Degree of user interactivity.</td>
</tr>
<tr>
<td>Consider necessary resources</td>
<td>• Intellectual capacity for VR technologies.</td>
</tr>
<tr>
<td></td>
<td>• Funding resources and amount of funding needed.</td>
</tr>
<tr>
<td></td>
<td>• Write funding proposals.</td>
</tr>
</tbody>
</table>

Note. Hanson and Shelton, 2008.

objects in the virtual world from a geometric, kinematics, physical, and behavioral standpoint as well as the crafting of integration software to allow all the pieces of the VR system to work and cooperate as intended. **VR engine**: the computer architecture needed to run the designed virtual environment. **User**: the person interacting with the VR system. And finally, **task**: the problem-based activity that is the center of the VR world
The challenge was understanding these components and identifying how the pieces fit into each category. My strategy was to rearrange the sequence of these components and give them titles to which I could better relate. As a result, my component list is as follows: (a) Learning goal, (b) Data and Integration, (c) VR activity, (d) Software and (e) Hardware (Table 8) (Hanson & Shelton, 2008). The user was not listed as an essential component because the establishment of learning goals takes into consideration the learner and the expected learning outcomes of the VR system.

I created a graphic based on my new understanding of the components of a VR system. As can be seen in Figure 10, the Learning Goals are listed as the most important component because the goal of the VR application dictates the decisions made for all other component systems. Data and Integration are titled and listed according to the actions that need to take place. As the user interacts with the virtual world, data is communicated to the computer that needs to be analyzed. Once analyzed, software that was specially created integrates all of the VR components so that information can be output or communicated back to the user, the VR Activity phase (Hanson & Shelton, 2008). This picture within Figure 10 represents the user interacting with the virtual world. It sits in the center of the cycle of interactivity and communication for my VR application.

Analysis of VR System

The enactment of this application required that the student put on the HMD to see the created 3D image of the human cranium (Figure 11). A webcam, situated closely
<table>
<thead>
<tr>
<th>Component</th>
<th>Questions to ask and answer</th>
<th>Examples of VR component items</th>
<th>Examples from existing VR projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning goal</td>
<td>• How will VR enhance this lesson plan? What is the added value of a VR system?</td>
<td>• Users will gain a greater sense of spatial and dimensional acuity.</td>
<td>• To practice and build skills for surgery (Mangan, 2000).</td>
</tr>
<tr>
<td></td>
<td>• What affordances (specially designed reification) in the virtual world will enable the</td>
<td>• Users will gain a greater understanding of complex conceptual relationships due to the</td>
<td>• To allow students to create and modify their virtual lab space to learn about human anatomy</td>
</tr>
<tr>
<td></td>
<td>expected learning?</td>
<td>multidimensional interactions with a VR system.</td>
<td>(Campbell, Rosse, &amp; Brinkley, 2001).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• To teach earth-sun relationships (Shelton &amp; Hedley, 2004).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• To control pain during wound care (Hoffman et al., 2004).</td>
</tr>
<tr>
<td>Data and integration</td>
<td>• How will the user see, feel and/or hear?</td>
<td>• Remote sensing equipment to track user movements</td>
<td>Pattern recognition tracking with ARToolKit and self-navigation (Shelton &amp; Hedley, 2004).</td>
</tr>
<tr>
<td>(input &amp; interactivity)</td>
<td>• Where is the data coming from?</td>
<td>• Haptic devices for sensory force feedback</td>
<td>Haptics using PHANToM (Mangan, 2000).</td>
</tr>
<tr>
<td></td>
<td>• How will data be analyzed and integrated?</td>
<td>• Sound displays</td>
<td>Fingertip controlled joystick (Hoffman, et. al, 2004).</td>
</tr>
<tr>
<td></td>
<td>• How will the data be rendered?</td>
<td>• Navigation and control systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Software programming to integrate all components to work and cooperate together</td>
<td></td>
</tr>
<tr>
<td>VR activity (output)</td>
<td>• What will the user see, feel and/or hear?</td>
<td>• 3D Objects</td>
<td>3D objects of the Solar System (Shelton &amp; Hedley, 2004).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Sensory feedback</td>
<td>3D objects of human body parts (Campbell et al., 2001).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Aural feedback</td>
<td>Snowworld and sounds of attack (Hoffman et al., 2004).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Feel tissue deformation (forcefeedback) (Mangan, 2000).</td>
</tr>
<tr>
<td>Component</td>
<td>Questions to ask and answer</td>
<td>Examples of VR component items</td>
<td>Examples from existing VR projects</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------</td>
<td>--------------------------------</td>
<td>----------------------------------</td>
</tr>
</tbody>
</table>
| Software  | ● What software and databases will be needed? | ● VR toolkits  
● Modeling  
● Input/Output device mapping | ● ARToolKit (Shelton & Hedley, 2004)  
● VirTools (Hoffman et al., 2004). |
| Hardware  | ● What hardware components will be needed? | ● VR engine  
● PC graphics architecture  
● Graphic display | ● I-glasses (Shelton & Hedley, 2004).  
● Water-friendly VR helmet (Hoffman et al., 2004)  
● 3D desktop computer interface (Campbell, Rosse & Brinkley).  
● Television screen (Mangan, 2000). |

*Figure 10. My instructional approach considering components of VR systems (Hanson & Shelton, 2008).*
nearby, would transmit the pattern to the computer, which would render the appropriate 3D image atop the pattern (Figure 12). I had a student try to attempt an injection while viewing this image (Figure 12). Observation revealed that when the student tried to interact with the 3D image, it would disappear (Figure 13). The image would disappear because the webcam’s line of sight to the image was interrupted and so the computer did not know what image to render when it could not detect the image. Therefore, the disappearance of the image was a problem with the rendering mechanics of this application. Therefore, there was a need to reconsider my technologic design for the next phase and eliminate my current method to render the 3D object.

The following figures (Figures 11 and 12) have been electronically altered to give the viewer an idea of what was intended. The activity depicted in Figure 12 could not actually occur since the image would disappear once the student interacted with it. Also, the clarity and detail of the 3D image was clear enough for this educational purpose. Therefore, we also needed to investigate a better 3D modeling software for our image. In
Figure 12. Student trying to attempt an injection using the pattern recognition rendering system.

Figure 13. Difficulties of pattern recognition rendering systems.

relation to my instructional needs, my intent was to allow for a 360-degree investigation of a 3D image of the human cranium. ARToolKit did not meet that need.

Because I worked with a small group of students, the analyses of interactions with the system were nonempirical, collegial, and anecdotal. The group discussed what worked and what didn’t and would troubleshoot solutions together. Basically, the VR
system that we built did not allow for 3D manipulatives or interaction; while there was
time to view the image and receive just-in-time feedback, there was not the ability for
self-controlled or iterative learning. Therefore, this system did not meet my needs for my
envisioned instructional intervention.

Students commented that they found the 3D object of the human cranium helpful
in understanding anatomy; however, they could not touch or interact with the object
because it would disappear once their hands interrupted the camera’s view of the pattern.
Also, the 3D object/graphic made with Daz studio was not realistic and could not be
altered during use (Figure 11). For Phase II, I needed help creating a 3D image that was
more realistic and could be altered. Other problems were centered on the need for force
feedback (haptics) when the user interacted with the 3D image.

**Summary of Results**

I greatly increased my knowledge base of VR technologies during Phase I. My
goal was to know enough to be able to create and operate a VR system. I was
successfully able to do this. In addition, I was able to put together a cogent request for
funding to continue with my research. My funding request was granted. Also, the bulk
of my research and literature review allowed me to formulate the theoretical grounding
section in this dissertation. The system that I created was rendered using ARToolKit,
iGlasses, a Daz Studio image, and a webcam. When I assessed this developed system
with what I had intended, I found it lacking in almost all the areas that I wanted my VR
system to possess. My students were not able to interact with the 3D image that I had
created. The image was a low-fidelity, low-quality image and did not provide the in-
depth analysis of anatomy that I had hoped. Also, the image could not be manipulated; in fact, when my students tried to interact with it, it would disappear. Therefore, self-controlled practice and iterative learning were not supported (Figure 14).

**Phase I: Exploratory - Discussion**

As part of the process of designing and developing a virtual system, I learned a lot about the challenges faced and strategies for solving those challenges. At the end of Phase I, the challenges were to find a better rendering system, create a high fidelity 3D manipulative object, purchase integration software, and simulate haptics. The strategies that I employed included the purchase and use of human magnetic trackers to render my world. Also, I hired developers to help create the virtual world that included that use of Maya software that could be used to create a realistic 3D image that could be manipulated. The developers I hired already used VirTools software that allowed all of my system components to integrate and work together. Last, I decided to simulate

*Figure 14. Phase I: Exploratory - research outcomes.*
haptics with the use of an anatomical model that the students could touch during their interface with LAMRS.

The theoretical constructs that frame my research were utilized at this phase to inform the design and development of my research goals, methodology and LAMRS for following phases. Chapter II outlines those theories that frame my research and Chapter III discusses my intent to answer my research questions as well as to produce shareable theories based on motor skills learning, learning with VR, and self-efficacy.

**Summary**

I learned a tremendous amount of information on VR systems and was able to successfully obtain a funding grant as well as publish a paper on my knowledge and experience. With this new information, I was able to successfully create a VR system for my instructional intervention. It was unfortunate that my initial attempt was unsuccessful for my research; however, the knowledge gained in this process was valuable and allowed me to move forward in a new direction.
CHAPTER V

PHASE II: PROOF OF CONCEPT

I discussed Phase I of research in Chapter IV. In this chapter, I will outline the design, development, and research for Phase II: Proof of Concept. During this phase, LAMRS was redesigned with specific learning goals in mind, exhibited built-in learner direction, and read and integrated data for the reification (to make real) of the virtual world and activity. The research questions were (a) In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity? (b) Will students develop better understandings with a virtual interface that allows them to direct their own learning? and (c) Will students be able to demonstrate the proper technique and verbalize a level of confidence for administration of local anesthesia after using the mixed-reality system? This chapter will include a description of research methods utilized as well as the discussion of research outcomes.

LAMRS involved the use of two magnetic trackers (one on the plastic syringe and one on the users head), a Dell laptop as the virtual engine, iglasses HMD, and an anatomical model lathered with liquid latex (Figure 15). Funding for this project did not allow for the kinematic modeling needed to provide sensory feedback within the virtual system. A modification was made to simulate haptics with an actual model of the bottom jaw and liquid latex. The 3D image was calibrated with the model of the bottom jaw. As the student moved toward the jaw and bone with the handheld syringe, they penetrated liquid latex to simulate the penetration of real tissue. The students navigated the system by moving their hands and head, which were both tracked. The researcher administered
Phase II

Timeframe: Spring 2007
Population: 10 Students
People: K Hanson, H Rose
Budget: $50,000

Research Questions
1. In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity?
2. Will students develop better understandings regarding the application of anatomical and technical concepts through iteration?
3. Will students be able to demonstrate the proper technique and verbalize a level of confidence for administration of local anesthesia after using the mixed-reality system?

Technological Design

Tracking:
Flock of Birds (2)

Navigation:
Plastic syringe with tracker.

Haptics:
Anatomical model of skull covered in liquid latex.

Navigation:
Key strokes/ Learner prompts

Integration:
VirTools

Software/Hardware

iGlasses
PC/SVGA

VirTools
VR ToolKit
Maya
Dell XPS M170
Laptop

Figure 15. Components of Phase II LAMRS.
keystrokes on the computer to provide the student with different views in the virtual world.

**Phase II: Proof of Concept – Design and Development**

Work on Phase II began in the Spring of 2007. Three undergraduate students worked with me; however, they worked more on the enactment of research methods, which involved 10 students as subjects, and not on the design and development at that time. I had been awarded a grant that allowed me to outsource my VR development needs to a design team: Firsthand Interactive, Inc. in Seattle, Washington. My budget at this phase was $50,000. That money was used mainly to purchase a different system for tracking the student in the virtual world since the pattern recognition system did not work for our purposes. Therefore, the hardware purchased was a human magnetic tracking system called the Flock of Birds. The Flock of Birds consists of a main box (the nest), which represents the center, or source, of the virtual world that the trackers circle around. These trackers were placed on the user’s head and on the syringe in the user’s right hand. Thus, the trackers represent the flock. Multiple trackers can be purchased to add to the flock while keeping the same nest.

A hand-held syringe was necessary as part of the virtual system so that the student held the actual tool that they would use when administering a live injection. It was decided that the syringe would need to be plastic due to the magnetic tracking system. We did not want the metal of the syringe to compromise the tracking. A wooden block was added to the back of the syringe to accommodate the 2X2-inch tracker. Also, the tracker that was placed on the user’s head would need to be stabilized with something
plastic that did not interfere with tracking. The best solution that I could find at the time was to Velcro the tracker to the top of an expandable women’s headband that could be affixed to each user’s head (Figures 16 and 17). Last, the main box of the Flock of Birds, referred to as “the source,” was embedded in a wooden frame with the anatomical model situation above it (Figures 16 and 17). This allowed the developers to create programming language that calibrated the user’s movements to the model in the virtual world. This calibration never changed since the model and the source were secure and calibrated to each other.

We bought a user license to use integration software called VirTools. Firsthand

Figure 16. Components of Phase II LAMRS: the virtual engine (A), the head mounted display (B), the source – under the wooden platform (C1), the Flock of Birds (C2), the head tracker (C3), the tracker on the syringe (C4), the anatomical model with liquid latex (D), graphics display (E), left hand for palpation (F) (Hanson & Rose, 2008; Hanson & Shelton, 2008).
Interactive, Inc. (Firsthand) had already purchased this very expensive software so they could use it for development purposes; we just had to buy a license that piggybacked on their user agreement. This solution was much more economical for my project. Firsthand also had the license to utilize Maya 3D programming software, so I did not need to purchase my own version of this software, which again saved money. It was recommended by Firsthand that I purchase a powerful laptop, Dell XPS M170, with an upgraded video card and RAM for my virtual engine. The rest of my available funds went to the design team at Firsthand. The developer that I worked with the most was Howard Rose who is credited with his work in the body of this dissertation.
The Phase II technological design involved the Flock of Birds for tracking, a plastic hand-held syringe with an embedded tracker for user navigation, and built-in prompts and keystrokes for external navigation. The integration software was VirTools, which integrated all VR system components to work together. Last, actual virtual haptics were outside my budget, so haptics were simulated using a physical anatomical model covered with liquid latex (Figures 16, 17, and 18).

Using Maya 3D programming software, Howard Rose developed a 3D image of the human cranium that could be manipulated to show a normal oral cavity, a translucent view of the oral cavity, and a bony view of the structures that were deep to the tissues of the oral cavity. In addition, prompts were built into the system for the inverted triangle to

![Image](image_url)

*Figure 18.* Depiction of the 3D image created using Maya for LAMRS.
help students understand this critical landmark for administering local anesthesia (Figure 18).

For enactment during this phase, the student would view the 3D image of a normal human head (Figure 19A). I allowed the student to orient to the anatomy and gain an awareness of the intraoral anatomical landmarks that are used for performing an injection (Figure 19B). Using a keystroke, I then showed a view of the same 3D object that was translucent to demonstrate how the oral tissues were superimposed over the bony landmarks that the student needed to understand to perform an injection (Figure 19C). The last view was of the bone and the nerves so that the student could gain a greater understanding of the spatial and dimensional relationships of the anatomy and injection technique (Figure 19D). This view was crucial because students could see, from a first person perspective, where the bone and nerves were actually located, compare it to the oral anatomy that they just saw, and make immediate comparisons. It is important to mention that the student saw the 3D image when they looked at where the anatomical model was located in the real world. Their view would adjust depending on where they looked and positioned their head.

Figure 19. 3D image manipulations of LAMRS. A, B, C, and D (Hanson & Rose, 2008).
Prompts, initiated with a keystroke, were built into LAMRS to assist the student in visualizing important landmarks. The student was able to identify the internal oblique ridge of bone seen in pink and the entire inverted triangle (Figure 20 outlined in yellow). In Figure 21, students were shown performing an injection on the anatomical model while using LAMRS. As mentioned, an anatomical model was added so that the student had something physical to touch when interacting with the system. I applied liquid latex to the model to simulate real tissue. Depicted in Figure 21B is a student attempt at an injection on the right side shown on the model and then in Figure 22, that same attempt is what the student saw in the virtual world.

The student can see, as in Figure 21A, her penetration site and then compare that with where she was positioned according to bony landmarks, as in Figure 22B. In Figure 22B, the student can see that they did not hit bone, but that their attempt was a little low in relation to the nerve. Therefore, their penetration would need to be higher on the inverted triangle to ensure that they do not miss the nerve when they anesthetize.

Figure 20. Identification of inverted triangle. A, B, and C. Screen shots of the built-in learner direction to identify landmarks (Hanson & Rose, 2008).
Figure 21. Student attempt at a left-side injection (A) and a right-side injection.

Figure 22. Virtual world views of the right-side injection with tissues visible (A) and then without (B).

**Phase II: Proof of Concept - Methodology**

The methodology included a one-group, pretest-posttest design, a posttreatment survey, as well as a qualitative analysis of student performance and student demonstration of shifts in learning. The pre and posttest exam (Appendix C) on concepts related to local anesthesia was given before and after treatment. The single time 20-
minute student interaction with LAMRS was digitally recorded and a posttreatment questionnaire was administered directly after treatment. The pretest served to determine student baseline understanding of techniques for the administration of the IA injection. I calculated one-tailed t tests, with an alpha level of 0.05, to test for significance between the pre and posttests. The posttreatment questionnaire related to learning and system design. Questions 1-9 dealt with the research guiding questions, while questions 10-16 related to LAMRS and the evaluation of system design, user presence, and need for future improvements (Figure 23).

I evaluated digital recordings according to a skills competency rubric for local

Figure 23. Graphic representation of Phase II Research Methods.
anesthesia and viewed to watch for epistemic shifts (or nodes) in thinking. I conducted this analysis with other expert dental hygiene educators (recruited from Weber State University dental hygiene faculty) based on a rubric (Appendix E) developed by a regional dental testing agency, the Western Regional Examining Board (WREB). We used sections three and four of the rubric for this evaluation. We gave the students a grade of “pass” or “fail” (as indicated on the rubric) as well as notations specific to their performance. My expert colleague and I participated in a calibration session prior to our observation of the research participants.

I evaluated for epistemic shifts in thinking following a standard format advanced by Strauss and Corbin (1990) and used by other researchers that I have studied (Barab et al., 2001; Shelton, in press). With this format, the researcher examines the data openly, looking for categories to emerge. Analysis progresses using a constant comparative approach until the categories are saturated or the data no longer provides new information (Herring, 2004). The categories are further examined for interconnectedness, thus building cohesion between the categories. These steps are referred to as open, axial, and selective coding (Creswell, 1998). Of the categories, the researcher looks for a central phenomenon or main category from which all others emerge (Figure 24 - a sample conditional matrix which is a graphic representation of relevant categories and connections).

Phase II: Proof of Concept - Results

Research results indicated support for research questions one and two with limited
support for question three. Students could identify the site of penetration for an IA injection and label the inside and outside walls of the inverted triangle better after their interactions with LAMRS. The majority of the students indicated that after using LAMRS, they understood that anatomical form dictated clinical technique and that they understood syringe angulations and the correlation to successful anesthetic technique. Students benefitted from that ability to see the 3D image from a 360-degree angle and could be manipulated to allow for multiple views. Student understanding of anatomical relationships improved while their technique did not change much. The majority of students indicated an increased level of confidence after using LAMRS and did feel that their technique improved after the experience. The expert analysis using the WREB rubric was not applied at this time because each student’s interaction with the system was different and adequate data on his or her performance was not captured. The following results are presented in the following order: pre/post test results, posttreatment survey outcomes, Excel data, expert rubric, and qualitative analysis.

Figure 24. Example of a conditional matrix.
Pre/Posttest

The difference in pre and posttest scores were considered statistically significant $t(9) = 2.89, p = 0.01$, one tailed, alpha level 0.05. The average score ($n = 10$) on the pretest was 8.6 out of 19 or 86% out of 100, with a standard deviation ($SD$) of 1.58; the average score on the posttest was 9.9 or 99% with a $SD$ of 0.32. The effect size was very small, with an average difference between pretest and posttest scores of 1.3 points. The decision to perform a $t$ test was made in order to identify those questions that students still did not understand but performed better on when taking the posttest. An item analysis revealed that students performed better on two questions, 6 and 7, on the posttest. Both these questions had to do with identifying the injection site for an IA injection on the left side and outlining and labeling the landmarks for that injection. An understanding of these tasks was an impetus for the LAMRS instructional intervention and considered an important outcome.

When a student takes a competency exam for local anesthesia, they need to demonstrate that they understand the correct placement of the syringe before inserting the needle into the tissue. If the student is not in the correct position before they insert the needle, examiners will tell them to stop and that they failed the exam. Therefore, the impact of understanding injection sites and landmarks could make or break a student’s performance on a licensure examination. In a live patient clinical situation, if a student does not perform an injection correctly—meaning correct placement and use of landmarks—then the patient may not experience numbness and the anesthesia would be deemed not successful. Therefore, the correct placement of the syringe and use of
landmarks does make an appreciable difference to patients.

**Posttreatment Survey**

On the postsurvey, questions 1-9 related to student perceptions of learning with LAMRS (Tables 9 and 10) and questions 10-16 had to do with the LAMRS system design (Table 11).

*Did you find that your technique for anesthesia improved as you interfaced with the mixed-reality system? Why?* In response to “why,” students indicated that they liked the ability for transparency, that they could see the layers of tissue and bone, that the system allowed for better visualization, and that it provided a better understanding of anatomy. Some drawbacks included that the system made it harder to see the angles, and it was hard to control the needle position.

Table 9

*Likert Type Questions*

<table>
<thead>
<tr>
<th></th>
<th>Questions 1, 2, and 5 (Scale 1-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Table 10

*Questions That Were Either Correct or Not Correct*

<table>
<thead>
<tr>
<th>Questions 3, 8, 9</th>
<th>Correct</th>
<th>Not correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>If anesthesia is not achieved with an IA, what could be the possible reasons for this failure?</td>
<td>9.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Explain your understanding of depth of needle penetration as it relates to the mandibular foramen for the IA injection.</td>
<td>6.75</td>
<td>3.25</td>
</tr>
<tr>
<td>Explain the rationale for premolar positioning with the IA injection.</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

*Was this technology helpful on a scale of 1-10 (10 being very helpful)?* The response: 10% (n = 10) responded with a score of 9-10; 70% indicated with a score of 7-8; 10% responded for 5-6; 10% responded for 3-4; and there were no responses for 1-2 (Figure 25).

*Do you have any suggestions for improvement on this technology?* Students recommended that the system be calibrated to allow for alignment of the 3D image and the anatomical model. They also suggested that we fix the technical problems (which had a lot to do with better calibration), improve realism by minimizing system errors, allow the user to get used to the system for a longer time, and make it easier to control the needle.

**Summary of Posttreatment Survey**

In summary, students indicated that they understood anatomical form and clinical technique as well as gained a higher level of confidence after their interaction with
Table 11

*Questions That Were Answered Yes, No, or Somewhat*

<table>
<thead>
<tr>
<th>Questions 4, 6, 7, 11, 12, 13, 15, 16</th>
<th>Yes</th>
<th>No</th>
<th>Somewhat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Were you able to see where and when to reposition the syringe / needle to get to the correct site of deposition?</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Did you find that your technique for anesthesia improved as you interfaced with the mixed-reality system?</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Were you more fully able to understand how proper syringe angulations leads to a successful injection?</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Was the 3D image realistic?</td>
<td>7</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Were you able to manipulate the 3D image without any significant problems?</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Do you feel your skills have improved from using this technology?</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Would you recommend this technology for future dental hygiene classes?</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Overall, was this an effective experience?</td>
<td>9</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
LAMRS. Students felt they could visualize the anatomy better after their experience and could correctly provide rationale for failure to achieve anesthesia. While a majority of students felt that their technique improved with LAMRS, some students felt that the interference of problems with the technology impeded their use and learning with the system. Overall, students felt there was value in the use of LAMRS and would recommend it for future dental hygiene classes.

**Expert Analysis with WREB Rubric**

When we started the process of applying the WREB rubric to student performance on the video, it was immediately evident that it would be difficult to assess technique, accuracy on penetration site, angle, and depth (Figure 26). Due to the fact that there were system errors that impeded user function with the system, we determined that adequate application of the WREB rubric at this time was not appropriate. Oftentimes the video
Figure 26. Components of WREB rubric used for Phase II evaluation.

did not capture closely enough a view that allowed us to adequately evaluate for pass or fail according to the rubric. Therefore, we took notes on each student’s attempt, but a grade of pass/fail was not given (Table 12). Student names have been changed to protect anonymity.

**Qualitative Analysis**

Looking for emergent categories, digital recordings were analyzed using a constant comparative approach (Herring, 2004). Categories were typed into a Microsoft Word document and then further data was categorized into like themes. Of the categories, I looked for a central phenomenon or main category from which all others emerged and then created a conditional matrix relating to those relationships as seen in Figure 27.

The initial categories that emerged related mostly to cranial views, anatomical structure, local anesthetic techniques, and built-in targets to gage physical positioning.
### Table 12

*Evaluator Notes on Video Analysis of Student Technique*

<table>
<thead>
<tr>
<th>Students</th>
<th>Outcome</th>
</tr>
</thead>
</table>
| Connie   | • Good  
|          | • A little to premolars, but not far enough  
|          | • Calibration of system off, student having problems |
| Karen    | • Appeared too shallow due to noncalibration |
| Melissa  | • Would have to evaluate penetration on computer |
| Kim      | • Good technique  
|          | • Looking at where tip ends up |
| Angela   | • Great technique even with calibration off  
|          | • Somewhat low for Left IA injection |
| Mindy    | • Good on right side  
|          | • Very nice  
|          | • Good angle with barrel |
| Sherrie  | • Comments on difficulty of needle  
|          | • Calibration off  
|          | • Cheek in the way  
|          | • Feels like needle doesn’t move the way she thinks she is moving  
|          | • High and shallow |
| Mary     | • Good  
|          | • Has had more experience with VR system |
| Tammy    | • Pretty good |
| Debra    | • Good  
|          | • Calibration off |
Figure 27. Conditional matrix of Phase II 2nd iteration research coding.

Observable behavior and conversation were centered on these topics. Further analysis revealed that the central phenomenon related to anatomy. Students wanted to understand anatomy on a general and specific level, anatomy as it relates to recommended techniques for anesthetic, and anatomy and the visualization of physical landmarks. The visualization of the anatomy was further intensified by the presentation of three training views: the normal oral cavity, a translucent layer, and bony landmarks with embedded innervations.

The categories that emerged can be seen in Figure 27. The main category is issues related to anatomy with subcategories as follows: oral views, spatial and dimensional relationships, recommended technique and educational targets. Further, third-level subcategories exist for each category. Table 13 represents examples of verbiage for each category.
Table 13

*Conditional Matrix of Categories Evident in Phase II*

<table>
<thead>
<tr>
<th>Categories</th>
<th>Subcategory</th>
<th>Voice</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral views</td>
<td>Sequence</td>
<td>Mindy</td>
<td>“I like that mouth and think it looks realistic but I don’t like that the cheeks don’t move.”</td>
</tr>
<tr>
<td></td>
<td>Each view unique</td>
<td>Me</td>
<td>“Can you see now where the nerves lie.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Connie</td>
<td>“Aahh, I can see that, very cool.”</td>
</tr>
<tr>
<td>Spatial and dimensional</td>
<td>General</td>
<td>Mary</td>
<td>“That is really cool when you take off the cranium and I can see the mandible anatomy better.” She practiced PSA and loved it.</td>
</tr>
<tr>
<td>relationships</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specific</td>
<td>Angela</td>
<td>“I really like this for learning the anatomy.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melissa</td>
<td>“I love looking at the anatomy like this.”</td>
</tr>
<tr>
<td>Recommended technique</td>
<td>Purpose</td>
<td>Sherrie</td>
<td>“This is cool. I can see why you tell us to stay close to the premolars.”</td>
</tr>
<tr>
<td></td>
<td>See flaws</td>
<td>Karen</td>
<td>“Ha ha. I was way off.”</td>
</tr>
<tr>
<td>Educational targets</td>
<td>Understanding</td>
<td>Me</td>
<td>“Look at the inverted triangle.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Connie</td>
<td>“Oh look, I can see that.”</td>
</tr>
<tr>
<td></td>
<td>Synthesis</td>
<td>Connie</td>
<td>“Oh, ok, I can see how the triangle relates to the mandibular foramen.”</td>
</tr>
</tbody>
</table>
The analysis of video data was difficult because much of the time was spent on orienting the student and working with system flaws. Also, the student interaction with the system was not structured; therefore, it was difficult to get a clear idea of what the student was thinking. For example, Karen made no comments at all when she interacted with LAMRS; she just played around and did what she wanted. Mindy showed no outward evidence of learning. These types of behavior made it difficult to determine if learning was taking place when the student interacted with the system. After that, we started asking questions; however, students like Melissa would only comment when questioned. I was hoping that the system would be so engaging that they would offer up a lot of spontaneous comments.

**Tracking One Student**

To clarify for my reader the experience of the student and the analysis done on her interaction with LAMRS, I have provided information that tracks one student. I have tracked “Connie,” showing her pre/posttest scores, her posttreatment survey responses, the expert evaluator outcomes (Table 14), as well as qualitative data that was found on her interactions with the system (Table 15). I chose to track Connie because I found her interactions with LAMRS to be interesting. Connie performed equally on the pre and posttest with a score of 100%. Her posttreatment survey responses indicated that she understood how anatomical form dictates technique and that she felt that she knows and can visualize the landmarks associated with administering an IA. She answered the question correct that using LAMRS, she could not see where and when she should reposition the syringe. On a scale of 1-5, she said her confidence level was a four. Her
Table 14

*Expert Evaluation of Connie with Rubric*

<table>
<thead>
<tr>
<th>Connie</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>A little to premolars</td>
</tr>
<tr>
<td></td>
<td>Calibration off</td>
</tr>
</tbody>
</table>

Table 15

*Qualitative Analysis of Connie’s Interactions with System*

<table>
<thead>
<tr>
<th>Connie</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Attempt going through check</td>
</tr>
<tr>
<td></td>
<td>Perfect angle on mandible</td>
</tr>
<tr>
<td></td>
<td>Good view of IA on left</td>
</tr>
<tr>
<td></td>
<td>Epistemic shifts evidences twice and had to do with the translucent views of the 3D image</td>
</tr>
</tbody>
</table>

Technique “sort of” improved with using LAMRS, and the biggest benefit was seeing where the needle was compared to the anatomical landmarks. She claimed to understand that proper syringe angulation led to a successful injection and could correctly verbalize the relationship of the syringe to the mandibular foramen and the premolars for an IA injection.

Connie felt that on a scale of 1-10 (with 10 being very helpful), LAMRS was a seven. She communicated that the 3D image was realistic, but that she could not manipulate the image without significant problems. Her skills improved “a little.” Her recommendations were to make it so that the needle was easier to control. In the end, she stated “yes!” that she would recommend this technology for future dental hygiene students and that the overall experience was effective.
Summary of Results

Support for research question one. The difference in two questions on the pre/posttest demonstrated that the students understood the identification of the site of penetration for an IA injection and could label the inside and outside walls of the inverted triangle better after their interactions with LAMRS. The majority of the students indicated at a level 3 or 4 that they felt they could visualize the anesthetic landmarks after use with LAMRS. Qualitative analysis of student interaction with LAMRS indicated that while students claimed to understand cranial anatomical structures and dimensional relationships, they exhibited multiple “aha” moments when they understood where bony landmarks were situated in relation to intraoral tissues. The 3D analysis of the cranial image was very helpful in understanding recommended technique, especially depth of penetration (Figure 28).

Support for research question two. The pre/posttest questions did not reveal any difference in scores, so these concepts were understood prior to the testing situation. On the posttreatment survey, the majority of the students indicated that after using LAMRS, they understood that anatomical form dictated clinical technique and that they understood syringe angulations and the correlation to successful anesthetic technique. The qualitative analysis revealed a pattern, or nodes, of thinking. This pattern was broken down into categories that had issued related to anatomy as the main category with oral views, spatial and dimensional relationships, recommended technique, and educational targets as subcategories. Analysis of interactions or comments in these categories support the supposition that students benefitted from that ability to see the 3D image from
Figure 28. Phase II: proof of concept research outcomes related to research question one.

360-degree angle and could be manipulated to allow for multiple views. Student understanding of anatomical relationships improved while their technique did not change much. There were episodes of planned activity and emergent activity that was both positive and negative (Figure 29).

Support for research question three. Again, there was no difference in pre/posttest scores for this section. The majority of students indicated an increased level of confidence after using LAMRS and did feel that their technique improved after the experience. The expert analysis using the WREB rubric was not applied at this time because each student’s interaction with the system was different and we did not have
adequate capture of their performance on the video data. Adjustments were made in the video technique for the next phase of research. In addition, it was difficult for the student to stay stationary in their attempt while they attempt to evaluate their technique from multiple angles and views. The categories on the rubric were helpful to provide feedback and performance could be evaluated, but a grade of pass or fail was not assessed (Figure 30).

**Phase II: Proof of Concept - Discussion**

The evidence suggests that learning outcomes were supported due to a difference in pre and posttest scores. Student learning could be attributed to the instructional

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*Figure 29. Phase II: Proof of concept research outcomes related to research question two.*
intervention. Limitations to using a pre/posttest approach without a control group could be considered a threat to internal validity. Other threats include a small sample size and a small effect size.

However, there were flaws with the system that impeded user presence. The post questionnaire revealed that students liked the options in the virtual world that allowed for the transparency of tissue and the visualization of landmarks for anesthesia, but felt it was difficult to navigate the needle and could not get a sense of where their left hand was to guide their technique. As a result, the analysis of the digital recording did not support
that LAMRS could be used to observe for skills competency and that episodes of epistemic shifts were rare.

In my analysis of Phase II LAMRS, I found that those needs that I had identified for my system were largely supported. Students were able to utilize a 3D image that could be manipulated for multiple views to promote cognition and association. They were able to initiate an attempt at an injection and evaluate their technique with me chairside providing them with just-in-time feedback. In addition, students were able to self-direct how they operated with the system, which promoted self-controlled practice and iterative learning. These outcomes were short of contributing to or advancing theory related to motor skills acquisition and self-efficacy.

During Phase II redesign analysis, crucial changes were identified for LAMRS. First, there was the act of further clarifying research questions with defined learner goals. Second, major improvements in calibration of the 3D image with the anatomical model were needed. Third, reification of the left hand was necessary since students were not able to visualize their left hand in the virtual world and kept poking themselves with the needle. Fourth, students needed to practice navigation with the syringe in their right hand and so needed the addition of an orientation phase in the world. Fifth, data collection was awkward and needed to be improved. Last, a new HMD that offered stereo-optic vision and a larger field of view needed to be acquired.

Moreover, changes were needed with research methods as well. An ability to collect Excel data on the tip and orientation of the needle on injection attempts was embedded and a structured sequence of student navigation, guided discovery, and use
with the system was needed (Appendix A). Last, the “nodes” of epistemic shift were evaluated at length and a structure emerged to use as a guide for the next phase of research.

It was interesting that Connie, even with all of her problems with the use of the system, still found the experience with LAMRS valuable and recommended its use for other students. While the problems with calibration impacted the posture of the student, they did not seem to have a problem with reconciling what they felt with what they saw.

Summary

While evidence of learning was supported, the ability to demonstrate competency for skills was not found. In addition, the ability to measure for competency according to the rubric was not realized. There were too many problems with the system that needed to be worked out before a student could demonstrate competency with the system.

Evidence did support that learning with VR can help students in making assessments and connections and impact their perceptions and understandings. However, further research would need to be completed to more significantly contribute to this theory.

In this chapter, I have provided a description of those research procedures employed during Phase II of research. I have presented my research questions as well as my methods, results, and discussion. In my analysis of the instructional intervention with Phase II LAMRS, I found that students were able to manipulate a 3D image in order to view from 360 degrees, as well as multiple images, the included depth to further support the cognition of spatial and dimensional relationships of the cranial anatomy. Further,
students were able to interact with the image and attempt an injection and evaluate their technique. The opportunity for experiential learning with just-in-time feedback was crucial and iterative learning took place. LAMRS was evaluated for design changes and recommendations were made for the next phase.
CHAPTER VI

PHASE III: REFINEMENT

As discussed in the previous chapter, design changes were recommended for LAMRS. In this section, I outline the educational and technological design research questions as well as explain the components of this iteration of LAMRS. I will clarify research procedures, data collection, and analysis techniques employed at this phase of research. The results will be presented with my discussion to follow. Conclusive statements will be at the end of this chapter. The research questions for Phase III were:

(a) In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity? (b) Will students develop better understandings regarding the application of anatomical and technical concepts through iteration? (c) Will students demonstrate the proper technique and verbalize a level of confidence for administering local anesthesia after using the mixed-reality system?

LAMRS, Phase III, involved the use of three magnetic trackers (one on the handheld syringe which is now metal, one on the data glove, and one on the HMD), a Dell laptop as the virtual engine, 1280 VR Helmut as the HMD, and an anatomical model lathered with liquid latex (Figures 31, 32, and 33). The 3D image was calibrated with the anatomical model of the bottom jaw. Under the anatomical model was a “source” (labeled C1 in Figure 33) that represents the center of the virtual world. Everything was tracked around this box and the student had to be looking at the model on top of this box to see the world. The students navigated the system by moving their hands and head. Either a research assistant or myself would administer keystrokes on the computer to
Figure 31. Phase III: Components of LAMRS.
Figure 32. Components of Phase III LAMRS: the virtual engine (A), Flock of Birds (C2), external monitor (E), monitor box for the new HMD (G), Head2Go splitter (H), and resting place for HMD (I).

Figure 33. Components of Phase III LAMRS: HMD VR1280 Helmut (B), the source (C1), Flock of Birds (C2), trackers on the syringe (C3), anatomical model with liquid latex (D), data glove (F), monitor box for the new HMD (G).
Phase III: Refinement – Design and Development

Phase III of research began in the Spring of 2009. Three undergraduate students worked with me on the research, with 20 students acting as research subjects. Those involved in design and development were Howard Rose from Firsthand Technologies, Inc. and myself. I had about $30,000 for this phase of system improvements. I purchased a used stereo optic HMD (Figure 34) called the 1280 VR Helmet to cut down on costs. With the inclusion of this new HMD, I would need to split my image for the stereo optic vision and so purchased a Head2Go Splitter, which I used with a previously owned external monitor. I purchased a data glove for the left hand so it could be included in the virtual experience. With this glove, I had to purchase a new tracker to add to my Flock so the hand could be tracked in world. The same Dell XPS M170 computer was used for the virtual engine and the same software, VirTools and Maya, were used for integration and the 3D image (Figure 7). The technological design included tracking with

Figure 34. VR1280 HMD from front (A) and side view (B) (head tracker can be viewed on top of side view) and data glove (C).
the Flock of Birds with three trackers instead of two, a stainless steel syringe with an embedded tracker, the same haptics with the anatomical model and latex, the same navigation with the syringe and keystrokes, as well as the same integration software with an updated version of VirTools.

For this phase the syringe was changed, the wooden platform was altered, a “norming” sequence was added, a “green stand-in” was added to represent each student attempt, and an output metric was recorded for each attempt. During Phase II the plastic syringe did not hold up well with multiple usages and so needed to be replaced with a media that was more substantive. We discovered that pure stainless steel did not affect the tracking of the Flock of Birds and so decided to work with a stainless steel syringe. We had to strategize how to attach the 2X2 tracker to the syringe. We ended up encasing the top portion of the syringe in acrylic and attached the tracker using nonferrous screws in the plastic (Figure 35). During Phase II, we also found that the wooden platform needed to be moved so that the student could see the different sides of the mouth, much like a patient moving their head from side to side. This was difficult to do with the corners of the wooden platform that encased the source. As a result, we rounded out the

*Figure 35. Stainless steel syringe with embedded tracker using acrylic and nonferrous screws.*
edges of the platform so that it could be rolled easily from side to side.

Another crucial design change included a practice sequence that I call “norming” to orient the student to the virtual system before they go into the educational application of LAMRS. In addition, we added to the system a “green stand-in” that appeared once a student attempted an injection in the world. This green stand-in would represent the student’s attempt, showing trajectory and angles of this attempt (Figure 26). This addition is an improvement because the student could view their attempt in the multiple views offered with LAMRS so the student could iteratively make attempts and try again based on their analysis. Last, a system was put in place to collect data on the student’s injection attempts. Each time the “enter” key is pressed to reveal the green stand-in line, data on the student’s place in the world is exported to an Excel document. The data represents the student’s location on an x-, y-, and z-axis in the world. This data was used to graph the student’s attempt later for further analysis (Figure 36).

During enactment for Phase III, students were shown, using LAMRS, a virtual

![Figure 36. “Norming” sequence with ball and bowl (A). In (B) the student cannot get over the lip of the bowl to put the ball inside the bowl.](image-url)
representation of a ball and a bowl and asked to pick up the ball with the syringe and place it in the bowl (Figure 36). In Figure 23B, the student has dragged the ball to the side of the bowl but keeps dropping it because she has not come up over the lip of the bowl. The intent of this exercise was to promote understanding that in the virtual world, structures have size and depth similar to the anatomical structures that will be viewed.

After “norming,” I allowed the student to look at the 3D image from all angles and views (translucent, etc.) so that he or she could develop a clear understanding of anatomy before starting. In Figure 37, I am turning the model so that the student can see the 3D image from 360 degrees.

In the next step, I used keystrokes to show the student built-in prompts to help them visualize the anatomical landmarks that make up the “inverted triangle,” a crucial understanding for performing this injection. Figure 38A is a screen shot of what the student saw to indicate the internal oblique ridge. If students do not remain cognizant of where this ridge is located, then they hit bone, or make osseous contact, during their

![Figure 37. A 360-degree examination of the 3D image.](image)
Figure 38. The pink line represents the internal oblique ridge (A). In (B) the student’s attempt met with bony contact.

injection and fail to achieve anesthesia (Figure 38B).

I asked the student to perform an attempt at an injection using the prompts for the inverted triangle and then view her attempt using multiple views. This exercise helps the student to understand that if she follows the landmarks correctly, she will not hit bone and not miss the nerve as it passes into the jawbone (Figures 39 and 40).

Next, I had the student attempt an injection without prompts. The following figures are screen shots to depict to the reader what the student would see on this attempt and then on her analysis of her attempt. As seen, when the student makes an attempt (Figure 41A) a green “stand-in” line is left to represent her attempt (Figure 41B). Then the student observes her attempt with intraoral tissues in place (Figure 42A) and again in the translucent view (Figure 42B). Next, she will view the green line in a bony view (Figure 43A) to see where she is located in reference to the correct deposition site indicated by a pink square seen in the virtual world (not seen in the figures). In Figure 44, the student has asked that the intraoral tissues be replaced so she can see the soft
Figure 39. Injection attempt using the built-in prompts for learner direction.

Figure 40. View of attempt with translucent tissue and bony tissue.

tissue landmarks again and compare it to her location on bone.

After another attempt the student analyzes her technique. She views the model from multiple angles and even gets a closer view (Figure 45 and 46). The student reverse engineered her attempt by going in reverse order in her analysis, ending with the green stand-in in the soft tissue view (Figure 47). The student indicated that it was helpful to analyze her attempt in every view provided.
Figure 41. Student attempt at a right IA injection in the real world and the virtual world.

Figure 42. Previous attempt viewed with tissue and translucent tissues.

As explained, $x$-, $y$-, and $z$-axis data are exported into an Excel file for later analysis. Figure 48 is a graphic representation of the three attempts conducted by a student. The blue line represents correct technique by which the student attempts are compared.
Figure 43. Previous attempt viewed with bony tissue as well as without the cranium but with intraoral tissue.

Figure 44. Previous attempt viewed with intraoral tissues and without.

Phase III: Refinement - Methodology

The instructional goals of the research questions again were conceptual competency of anatomical and spatial relationships, demonstrated competency of anatomical and spatial relationships, and investigation to the potential degree that mixed-reality has for the clinical practice of anesthesia administration. Certain questions on
both the pre/posttest and posttreatment survey served to support the attainment of conceptual and demonstrated competency as seen in Table 14. The use of Excel data specifically related to conceptual competency of anatomical and spatial relationships and provided information for demonstration of competency and the investigation to the potential degree that mixed-reality has for the clinical practice of anesthesia. The qualitative evaluation of digital recordings provided support for demonstrated
Figure 47. Student look at her attempt at the end of her analysis with intraoral tissues put back in place.

Figure 48. Graph of student attempts in world captured with Excel data.
competency, but also provided better understanding of the use of mixed reality in clinical practice. The evaluation of the local anesthesia technique with the skills rubric substantiated the third instructional goal, and I used those findings to triangulate findings with instructional goals one and two (Figure 49). Institutional review board (IRB) approval was granted by Weber State University for this research (Appendix F).

**Pre/Posttest**

As mentioned, students completed a posttreatment questionnaire with questions
that related to the research guiding questions (Appendix D). In addition, there were questions on the postinterview that related to system design that helps to direct future improvement of LAMRS. Questions 1-9 dealt with the research guiding questions, while questions 10-16 related to LAMRS to evaluate system design, user presence, and need for future improvements. I analyzed the data using descriptive statistics.

**Posttreatment Survey**

The posttreatment questionnaire related to learning and system design. Questions 1-9 dealt with the research guiding questions, while questions 10-16 related to LAMRS and the evaluation of system design, user presence, and need for future improvements (Figure 49).

**Expert Analysis with WREB Rubric**

I conducted quantitative analysis with an expert dental hygiene educator (recruited from Weber State University dental hygiene faculty). We evaluated the student’s skill for administering local anesthesia based on a rubric (Appendix E) developed by a regional dental testing agency, the Western Regional Examining Board (WREB). Only sections three and four of the rubric were used for this evaluation. We gave the students a grade of “pass” or “fail” (as indicated on the rubric) as well as notations specific for each performance. My colleague and I participated in a session to ensure interrater reliability prior to our observation of the student performance on video. During this session we both viewed the video from Phase II: 2nd iteration research and shared our findings. Once we agreed on our findings at least 75% of the time, we
conducted our analysis.

**Qualitative Analysis of Digital Recordings**

The qualitative analysis of digital recording followed the same qualitative methodology presented in Phase II analysis of enactment outcomes. Further, I used the conditional matrix of emergent nodes that resulted from Phase II research to guide my analysis on this phase. I evaluated for epistemic shifts in thinking following a standard format advanced by Strauss and Corbin (1998) and used by other researchers that I have studied (Barab et al., 2001; Shelton, in press). With this format, the researcher examines the data openly while looking for categories to emerge. Analysis progresses using a constant comparative approach until the categories are saturated and the data no longer provide new information. The categories are further examined for interconnectedness; thus, building cohesion between the categories. These steps are referred to as open, axial, and selective coding (Creswell, 1998). Of the categories, the researcher looks for a central phenomenon or main category from which all others emerge.

**Phase III: Refinement - Procedures**

Phase III of research was conducted at Weber State University’s dental hygiene clinic using a dental chair and LAMRS. Students were recruited from the Weber State University Dental Hygiene Program; they were all female between the ages of 20 and 55 years old. The research design was a one-group (20 senior dental hygiene students) convenience sample, pre/posttest study. My data collection techniques included a pre and posttest, administered just before and after treatment (one-tailed t tests, with an alpha
level of 0.05), a posttreatment questionnaire, digital recordings of student interactions with LAMRS, and an Excel spreadsheet. The spreadsheet included coordinates for the needle tip location and orientation of each injection attempt in the virtual world as well as the time it takes to complete each attempt. This information was used to make comparisons for each attempt and to draw conclusions on the student’s technique for administering local anesthesia. All interactions with LAMRS were digitally recorded for the analysis of skills competency and potential episodes of epistemic shifts.

I scheduled students for two 20-minute sessions with LAMRS. Instructional focus was on techniques for administering a cranial block injection for the lower jaw, referred to as the IA injection, on both the right and left sides of the mouth. Research sessions were scheduled on April 6, 10, and 13, 2009. I directed the student’s experience with LAMRS to provide guided discovery and just-in-time feedback as well as to take advantage of built-in instructional design to identify oral anatomical landmarks.

The students experienced one 20-minute session with LAMRS during which they were guided through stages of discovery: orientation, visual acclimation, landmark identification, and local anesthesia (LA) performance attempts (Appendix A). Students had the opportunity to orient to LAMRS by performing a simple task. I called this sequence “norming” because students felt more normal in their movements after this task. I showed the student a virtual representation of a ball and a bowl and ask them to pick up the ball with the syringe and place it in the bowl. At times, the student would drag the ball to the side of the bowl but drop it because she had not come up over the lip of the bowl. This exercise was to help the student understand that in the virtual world,
structures have size and depth similar to the anatomical structures that they would be viewing.

After “norming,” I allowed the student to look at the 3D image from all angles and views (translucent, etc.) so that she could develop a clear understanding of anatomy before she started. In the next step, I showed the student built-in prompts to help them visualize the anatomical landmarks that make up the “inverted triangle,” a crucial understanding for performing this injection. If students did not remain cognizant of where this ridge is located, they hit bone, or made osseous contact, during their injection and failed to achieve anesthesia.

I asked the student to perform an attempt at an injection using the prompts for the inverted triangle and then view her attempt. As I mentioned, the inverted triangle is an invisible triangle that is made up of the pterygomandibular raphe on the palatal side with the internal oblique ridge on the cheek side, the mandibular retromolar pad on the bottom, and the maxillary occlusal plane on the top (see Appendix A). This exercise helps the student to understand that if she follows the landmarks correctly, she will not hit bone and not miss the nerve as it passes into the jawbone.

Coordinates for the needle tip location and orientation of each injection attempt in the virtual world was collected in an Excel document for later analysis. I gave the student the opportunity to perform another injection after viewing their attempt. The same process as just described was followed so the student could reflect on her next attempt.
Phase III: Refinement - Results

Research results indicated support for all three research questions. Students could identify the site of penetration for an IA injection and label the inside and outside walls of the inverted triangle better after their interactions with LAMRS. The utilization of time per injection attempt decreased for attempts on both sides. Qualitative analysis revealed “aha” moments for the students as they interacted with LAMRS. The 3D analysis of the cranial image was very helpful in understanding recommended technique, especially depth of penetration. Students indicated that after using LAMRS, they understood that anatomical form dictated clinical technique and that they understood syringe angulations and the correlation to successful anesthetic technique. The qualitative analysis revealed that students benefitted from that ability to see the 3D image from a 360-degree angle and could be manipulated to allow for multiple views. Student understanding of conceptual relationships improved while their technique did not change much. The majority of students indicated an increased level of confidence after using LAMRS and felt their technique improved after the experience. The expert analysis of student performance based on a rubric revealed an average pass rate of 62%. Upon follow-up, students indicated that their understanding of anatomy, based on their experience with LAMRS, has impacted their performance for administering local anesthesia in private practice. Conversations with expert dental examiners thought the idea of a local anesthesia simulation was valuable for practice but would not replace live patient competency exams. The following results are presented in the following order: pre/posttest results, posttreatment survey outcomes, Excel data, expert rubric, and qualitative analysis.
Pre/Posttest

On the pretest, students scored a mean of 5.7 out of 9, or 64%, with an SD of 1.04. On the posttest, students scored a mean of 7, or 79%, with an SD of 1.26. With a pretest score of 64% and a posttest score of 79%, student increased their score by 15%, or 1.3 points. A t test was performed on the pre and posttest data and revealed that the difference between scores was statistically significant, \( t (19), p = 0.00 \), one tailed, alpha level 0.05. While the \( t \) test was statistically significant, the effect size was very small, with an average difference between pretest and posttest scores of 1.3 points.

Further analysis of the pre/posttest scores revealed that 75% (\( n = 20 \)) of student posttest scores were higher than the pretest scores, 15% of student pre and posttest scores were the same, and 10% of student posttest scores were actually lower than the pretest score. The same pre/posttest tool was used for Phase III that was used for Phase II. I cannot account for the fact that the Phase III students got lower scores than the Phase II students unless it has to do with the increase in sample size. Phase II had 10 students and Phase III had 20. In reference to the fact that students generally performed well on both the pre and posttests, I hypothesize that the students performed well on this test because they are high-academic performing students that have been accepted into a merit-based dental hygiene program. It is difficult to find a time when they do not perform well on tests.

Test questions were further broken down to those that support each research question (Tables 16, 17, and 18). Questions six and seven were the only questions that had a significant difference between the pre and posttest responses. Question six stated,
### Table 16

**Pre/Posttest Questions That Related to Research Question One**

<table>
<thead>
<tr>
<th>Pre/Posttest question</th>
<th>Pretest scores</th>
<th>Posttest scores</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Which of the following landmarks are associated with an inferior alveolar injection? Circle all that are appropriate.</td>
<td>9/20 students got this correct</td>
<td>9/20 students got this correct</td>
<td>None</td>
</tr>
<tr>
<td>2. Explain why you choose to eliminate any landmarks from your last answer.</td>
<td>9/20 students got this correct</td>
<td>9/20 students got this correct</td>
<td>None</td>
</tr>
<tr>
<td>6. Identify the injection site for the IA on the left side with an X in the correct spot.</td>
<td>11/20 students got this correct</td>
<td>14/20 students got this correct</td>
<td>$p = .04$</td>
</tr>
<tr>
<td>7. In the picture above, outline the inverted triangle for the right IA and identify the buccal and lingual walls of the triangle.</td>
<td>2/20 students got this correct</td>
<td>5/20 students got this correct</td>
<td>$p = .08$</td>
</tr>
</tbody>
</table>

### Table 17

**Pre/Posttest Questions That Related to Research Question Two**

<table>
<thead>
<tr>
<th>Pre/posttest question</th>
<th>Pretest scores</th>
<th>Posttest scores</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Describe the relationship of your syringe needle to the mandibular foramen.</td>
<td>20/20 students got this correct</td>
<td>20/20 students got this correct</td>
<td>None</td>
</tr>
<tr>
<td>9. How would you correct this technique?</td>
<td>20/20 students got this correct</td>
<td>20/20 students got this correct</td>
<td>None</td>
</tr>
</tbody>
</table>
Table 18

Pre/Posttest Questions That Related to Research Question Three

<table>
<thead>
<tr>
<th>Pre/Posttest question</th>
<th>Pretest scores</th>
<th>Posttest scores</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. The mandibular canine incisor is planned for root debridement, select the injection necessary to provide complete anesthesia.</td>
<td>19/20 students got this correct</td>
<td>19/20 students got this correct</td>
<td>None</td>
</tr>
<tr>
<td>5. What injection would you perform to anesthetize #28?</td>
<td>20/20 students got this correct</td>
<td>20/20 students got this correct</td>
<td>None</td>
</tr>
<tr>
<td>8. Identify the technique error associated with this pictured of the IA injection.</td>
<td>20/20 students got this correct</td>
<td>20/20 students got this correct</td>
<td>None</td>
</tr>
</tbody>
</table>

Identify the injection site for the IA on the left side with an “X” in the correct spot. On the pretest, 55% (n = 20) got the question correct. On the posttest, 70% got the question correct with a statistically significant result of $t(19), p = 0.04$, one tailed, alpha level 0.05. Question seven stated, Outline the inverted triangle for the right IA and identify the buccal and lingual walls of the triangle. On the pretest, 10% (n = 2) got the question correct. On the posttest, 25% got the question correct with a nonstatistically significant score of $t(19), p = 0.08$, one tailed, alpha level 0.05.

As mentioned in Phase II, the ability to demonstrate correct placement of the syringe before inserting the needle into the tissue is critical on a competency based exam. If the student is not in the correct position before they insert the needle, examiners will tell them to stop and that they failed the exam. Therefore, the impact of understanding injection sites and landmarks could make or break a student’s performance on a licensure
examination. In a live patient clinical situation, if a student does not perform an injection correctly, meaning correct placement and use of landmarks, then the patient may not get numb and the anesthesia would not be successful. Therefore, the correct placement of the syringe and use of landmarks does make an appreciable difference to patients.

_If anesthesia is not achieved with an IA, what could be the possible reasons for this failure? Why?_ The response: 100% (n = 20) were correct with very simple to more complex rationale. Everyone knew that failure to achieve anesthesia was the result of missing the nerve, but an explanation of why they missed the nerve was a more compelling response. Students described that the syringe angulation was not correct and that the depth of penetration was not far enough. Osseous contact was met too soon. It was clear that the students were confusing the mental foramen with the mandibular foramen. Students further extrapolated that failure to anesthetize could be due to the tissue pH brought on by excessive infection. Students cited different anatomy as a potential etiology for an unsuccessful injection. Table 19 is a depiction of those test questions that were answered correctly or incorrectly.

**Posttreatment Survey**

On the postsurvey, questions 1-9 (Table 20) related to student perceptions of learning with LAMRS and questions 10-16 had to do with the LAMRS system design (Table 21).

Since only 65% stated that the LAMRS system improved their technique, it is important to know about the student responses. Students stated that it was nice to “see where I’m aiming for with and without soft tissue” and “it was helpful to see after the
Table 19

*Questions That Were Answered Correctly or Not Correctly*

<table>
<thead>
<tr>
<th>Questions 3, 8, 9</th>
<th>Correct</th>
<th>Not correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>If anesthesia is not achieved with an IA, what could be the possible reasons for this failure?</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Explain your understanding of depth of needle penetration as it relates to the mandibular foramen for the IA injection.</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Explain the rationale for premolar positioning with the IA injection.</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 20

*Composite Scale Questions*

<table>
<thead>
<tr>
<th>Questions 1, 2, and 5 (Scale 1-5)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>On a scale from 1-5 (5 being the highest) how well do you understand how anatomical form dictates techniques for anesthesia?</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>How well do you feel you know and can visualize the anatomical landmarks?</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>On a scale of 1-5 (5 being very confident) how confident do you feel giving injections?</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Questions 4, 6, 7, 11, 12, 13, 15, 16</td>
<td>Yes</td>
<td>No</td>
<td>Somewhat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----</td>
<td>----</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were you able to see where and when to reposition the syringe / needle to get to the correct site of deposition?</td>
<td>15</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did you find that your technique for anesthesia improved as you interfaced with the mixed-reality system?</td>
<td>13</td>
<td>5</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were you more fully able to understand how proper syringe angulations leads to a successful injection?</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the 3D image realistic?</td>
<td>12</td>
<td>3</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were you able to manipulate the 3D image without any significant problems?</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you feel your skills have improved from using this technology?</td>
<td>14</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Would you recommend this technology for future dental hygiene classes?</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall, was this an effective experience?</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
tissue is removed to see the landmarks.” However, other comments were “it was kind of hard to know where my left hand was” and “I feel like I couldn’t really see what I was doing so felt unsure of myself.” While the majority of the comments were positive, the negative comments focused on problems that emerged with the technology and educational design that could be solved for on a next iteration.

Was this technology helpful on a scale of 1-10 (10 being very helpful)? The response: 15% (n = 20) indicated a level of 10; 30% indicated level 9; 25% indicated level 8; 5% indicated level 7; 15% indicated level 5; 5% indicated level 3; 5% indicated level 2; and no responses were given for levels 6, 4, and 1 (Figure 50).

Students provided some written comments to this question. The most often cited difficulty with LAMRS was the visualization of the left hand and the left hand data glove. The HMD posed problems with the right eye (visual display) episodically losing the

![How helpful was this technology?](image)

*Figure 50. Survey Question on the Helpfulness of the Technology.*
video feed and that there needed to be a longer period to get used to the system. One student felt it was more difficult than a real patient and that the 3D image not was aligned with the physical model.

Comments to this question included that LAMRS would have been more helpful to learn anatomy on first after which technique could have been tried. Another comment said that it did help to better visualize the IA. However, one student felt she liked peer-practice better and didn’t need a simulation.

Do you have any suggestions for improvement on this technology? Responses ranged from making the 3D image clearer, calibrating the left hand for better utilization, providing more time for orientation, adding more realistic tissue, and more closely aligning the 3D model with the physical model. There were problems during this phase of research with the system running consistently; many students commented that this needed to be fixed.

Summary of posttreatment survey. In summary, students indicated that they understood anatomical form and clinical technique as well as gained a higher level of confidence after their interaction with LAMRS. Students felt they could visualize the anatomy better after their experience and could correctly provide rationale for failure to achieve anesthesia. While a majority of students felt that their technique improved with LAMRS, some students felt that the interference of problems with the technology impeded their use and learning with the system. Overall, students felt that there was value in the use of LAMRS and would recommend it for future dental hygiene classes.
Analysis of Excel Data

Each time a student attempted an injection, a research assistant would press “enter” to record that attempt in Excel. Two sets of data were recorded that included coordinates for an $x$-, $y$-, and $z$-axis. The $x$-axis represents the horizontal plane, the $y$-axis represents the vertical plane and the $z$-axis represents the tilt forward and backward in a three dimensional plane. The first set of $x$, $y$, $z$ coordinates recorded in Excel were for the location of the needle tip and the second set were of the location of the center of the syringe. Proper injection technique requires the student to be parallel with the occlusal plane of the bottom jaw with the syringe located over the premolars opposite the injection site (as can be seen by the blue line in Figure 51). If the student attempt is not over the premolars then her angle will not be correct on the $z$-axis. The $z$-axis is represented with a thin gray line on the graphs that goes at an angle with an arrow to demonstrate that it is

Figure 51. Two attempts for three students graphed.
perpendicular to the horizontal x-axis (Figure 52).

This purpose of the Excel data was to know exactly where the student was in the virtual world for each attempt. Part of the competency-based exams has to do with angle and depth of penetration. The Excel data represents an output matrix that allowed evaluators to go back see exact data about the student’s attempt.

Figure 52 depicts how each attempt looks graphed according to the recorded Excel coordinates. Three students’ attempts at two injections are graphed along with the blue master line to indicated correct technique. The blue line is the master by which all student attempts are evaluated. The tip of the needle should be on the nerves that can be seen in Figure 66 and the center of the syringe should be horizontal with the occlusal plane of the bottom teeth, and over the premolars. It is difficult to graph three dimensions on a two-dimensional figure. All the lines in the graph are the same length;

\[
\text{Figure 52. Two attempts by three students graphed (with z-axis represented).}
\]
some appear shorter or longer depending on the coordinates for the center of the syringe on the $z$-axis. The shorter the line, the closer to the front of the mouth, over the incisors, the syringe is located. When the line is shorter, the location of the needle tip often looks higher on the $y$-axis when, in fact, it is deeper on the $z$-axis, too far into the mouth. Figure 53 is the same as Figure 54 with the $z$-axis represented by a thin gray line.

As noted, the blue line represents a correct attempt, by which others are evaluated. The green lines represent Anna’s attempts, the lower line was not parallel with the occlusal plan and was too deep ($z$-axis) on the needle tip and too anterior on the syringe angle, which indicates that she was not over the premolars, but over the incisors. The upper line was more parallel on the occlusal plane but she was still too far anterior on the $z$-axis. The yellow lines are close to the correct location on the $z$-axis but not parallel with the occlusal plane. The red lines are both too shallow on the $x$-axis and too high on

*Figure 53. Combined students attempts on the right IA.*
In Figure 53, I have graphed the $x$- and $y$-coordinates of all of the student attempts at a right IA injection. As can be seen, the students managed to correctly place the needle tip near the nerves more times than they got the syringe angle correct. Figure 54 represents that students were far less successful at achieving the correct syringe angulations.

Table 22 outlines the percentage of the time that the students were within 4mm of where the tip of the syringe should be placed, were within an acceptable zone for the angle of the center of the syringe, and when both the tip and the angle occur correctly at the same time. The tip of the syringe was most often correct on the first attempt for the right IA and on the first and last attempt for the left IA (Figure 55). For the right IA, the
Table 22

Percentage of Times That an Attempt Was Correctly Placed for the Tip and Syringe Center

<table>
<thead>
<tr>
<th></th>
<th>Attempt 1 (n = 60)</th>
<th>Attempt 2 (n = 60)</th>
<th>Attempt 3 (n = 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Tip</td>
<td>100%</td>
<td>85%</td>
<td>95%</td>
</tr>
<tr>
<td>Syringe</td>
<td>15%</td>
<td>15%</td>
<td>30%</td>
</tr>
<tr>
<td>Both</td>
<td>20%</td>
<td>15%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Note. 3 attempts per student times 20 students = 60 attempts.

Figure 55. Correct needle placement
percentage of times that the tip was correctly placed went down with each attempt. For the syringe angle, students performed better on their second attempt on the right side and on the first and last for the left side (Figure 56). Because the syringe angle was more difficult to achieve and was less often correctly placed, those numbers dictate the percentage of times that both the tip and syringe were correct during the same attempt (Figure 57). It appears that the right IA was an easier and more often correct injection than the left IA.

Each student attempt was timed and recorded to evaluate for relevancy. With a look at average times per injection attempt, it appears that the student’s time per attempt decreased with each attempt (Table 23 and Figure 58).

The percentage of times that students performed the most correct attempt for the right IA was on the second attempt. The last attempt was most often correct for the left IA.

*Figure 56. Correct angle placement.*
Figure 57. Correct needle and angle placement.

Table 23

<table>
<thead>
<tr>
<th>Time to Complete Each Attempt</th>
<th>Attempt 1</th>
<th>Attempt 2</th>
<th>Attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Time</td>
<td>11.8 sec</td>
<td>9.6 sec</td>
<td>10 sec</td>
</tr>
</tbody>
</table>

Note. n = 60

IA (Table 24 and Figure 59).

The percentage of times that the third injection was in the middle of the first two was 50% on the right side and 45% on the left. The percentage of times that the third attempt was the most correct attempt was 35% on the right and 50% on the left. The percentage of times that penetration was on track to be correct for the needle tip was 98% on the right and 97% on the left.
Table 24

Percentage of When Each Student’s Most Correct Attempt Fell

<table>
<thead>
<tr>
<th></th>
<th>Attempt 1</th>
<th>Attempt 2</th>
<th>Attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most correct</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>70%</td>
<td>75%</td>
<td>35%</td>
</tr>
<tr>
<td>Left</td>
<td>30%</td>
<td>45%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Most often, students were not parallel with the occlusal plane and were, at times, very far off course (Figure 60). Attempts 1 and 2 were too far over the molars (too deep on the z-axis) and not parallel. Whereas, on attempt 3, the needle tip was too far to the midline of the mouth and the angle of the syringe was off for all angles – most definitely too far anterior on the z-axis.

In Figure 61 I wanted to emphasize how a student can be in the correct location for the needle tip and not correct on the angle of the syringe. In Figure 61 all of the
Figure 59. Attempt when most correct injection occurred.

Figure 60. Examples of one student’s three attempts.
Another example of one student’s three attempts.

attempts for this student were too low, not parallel with the occlusal plane, and too far distal on the z-axis.

Expert Evaluation of Student Attempt Using a Rubric (Video)

My colleague and I applied the rubric for local anesthesia technique to the pictures and screenshots that were taken during the students’ interaction with LAMRS. There were problems with using the rubric during Phase II, so I made sure that during this phase the student videotaping was instructed to get a good view of each student’s attempt as well as capture the image on the screen during her attempt as well. This strategy for videotaping made a difference in images that could be evaluated for performance.

Traditional use of the rubric has been to evaluate student performance while standing next to the student, positioning for the best view possible. With LAMRS we
could judge the traditional clinical view of a student’s attempt as well as judge the attempt in the bony view, which cannot be done in traditional testing. Each attempt was judged as pass or fail in both the clinical and bony view, independently of the others. There was a pass rate of 47 out of 60, or 80%, on the right side using the clinical view and a pass rate of 42 out of 60, or 70%, in the bony view. On the left side, 31 out of 60, or 52%, attempts passed in the clinical view and 28 out of 60, or 47%, in the bony view. Using a Fisher’s Exact Test to analyze a 2X2 contingency table of categorical data, I found that the difference between pass and fail in the clinical and bony view were statistically nonsignificant (Table 25). A nonsignificant result means that the evaluations of pass or fail in either view, clinical or bony, are pretty closely correlated and are therefore comparable.

Because the evaluations of pass or fail in the clinical and bony view are

Table 25

A 2X2 Contingency Table: P Values from Fisher’s Exact Test

<table>
<thead>
<tr>
<th></th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right clinical</td>
<td>47</td>
<td>13</td>
</tr>
<tr>
<td>Right bony</td>
<td>42</td>
<td>18</td>
</tr>
<tr>
<td>Left clinical</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>Left bony</td>
<td>28</td>
<td>32</td>
</tr>
</tbody>
</table>
comparable, the attempts were combined with each other for analysis. The result was that student attempts were graded as “pass” in 148 attempts out of a possible 240, which is an overall pass rate of 62%; that is about 7 out of 12 correct attempts for each student. The range of scores was from 2 passes to 12 passes, or a 17-100%. The mode was \( \frac{7}{12} = 58\% \). Judgment for the clinical view and boney view coincided 98 out of 240 times, or 41% of the time. A passing scores was assessed 64 out of 240 attempts, or 27% of the time, and attempts were assessed a failing grade 34 out of 240 times, or 14% of the time.

**Comparison of Excel data and expert analysis.** The analysis of Excel data revealed that students passed their injection attempts on the right side 31 out of 60 times, or a 52% pass rate and 13 out of 60 times, or a 22% pass rate on the left side. When using the Fisher’s Exact Test on the rubric data for both right and left sides, the result was statistically significant for either view. Also, when the overall pass rate for the rubric data was compared to that of Excel, the result was again statistically significant (Table 26). This outcome is indicative that the two tools for analysis, the rubric and Excel data, are not comparable. The number of pass/fails are too divergent to be considered aligned.

**Comparison of LAMRS pass rates and WREB pass rates.** As mentioned, the results of Phase III pass rates indicated a 74% pass rate with the rubric and a 44% with the Excel data. With a vision for using VR technologies for competency-based testing in the future, comparing pass rates with LAMRS and traditional testing is pragmatic. The pass rate for those students who participated in the LAMRS research and took the WREB exam Spring 2009 was 97%. One out of thirty students failed. This student passed LAMRS testing with a pass rate of 100% for both the rubric and the Excel data.
Table 26

*Fisher’s Exact Test and P Values*

<table>
<thead>
<tr>
<th>Average pass rate</th>
<th>Pass</th>
<th>Fail</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubric right side</td>
<td>45</td>
<td>15</td>
<td>0.01</td>
</tr>
<tr>
<td>Excel data right side</td>
<td>31</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Rubric left side</td>
<td>30</td>
<td>30</td>
<td>0.00</td>
</tr>
<tr>
<td>Excel data left side</td>
<td>13</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Rubric combined</td>
<td>74</td>
<td>46</td>
<td>0.00</td>
</tr>
<tr>
<td>Excel combined</td>
<td>44</td>
<td>76</td>
<td></td>
</tr>
</tbody>
</table>

In 2007 and 2008, the students’ WREB pass rate was 93%, with two students failing each year.

**Professional opinion.** I spoke with a professional statistician, Sarah Toevs, about the inconsistency in the number of pass/fails with the rubric and the Excel data. Dr. Toevs is a dental hygienist and was a dental hygiene educator for over 10 years and so understands the WREB rubric and competency-based testing. She currently is faculty at University of Idaho in health studies and has her doctorate in statistics. She opined that it is premature to try to align as assessment tools the rubric and the Excel data. She stated
that in another iteration, perhaps where I am comparing skills acquisition and technique using an experimental and control group design, it would be more appropriate to combine the use of the two assessment tools. Also, as long as the WREB exam remains a live clinical experience, the use of the rubric, which is not as specific as the Excel data, will have to be used to look for global demonstrations of technique. The Excel data are a useful output metric that can provide information to the students while they are learning but should not be compared to the rubric, which is used to evaluate clinical performance.

**Qualitative Data Analysis**

During Phase II, I specified categories that related to learning and to technology and only further categorized the learning subcategories. However, for Phase III, I choose to include learning and technology under the same main category of *Using LAMRS* because there was so much more data available to analyze and so much opportunity for students to engage and talk about what they were experiencing. As mentioned in Phase II, during my qualitative analysis, I looked for emergent categories and analyzed the digital recordings using a constant comparative approach. The difference with this phase was that I utilized the Phase II qualitative outcomes as a template to identify nodes of dialogue that fit into those categories, leaving room for new categories to emerge.

The categories for qualitative analysis that were identified in Phase II were present at Phase III but blended together more. This blending may be due to the fact that students had a longer time to use the system and self-direct their analysis by telling my research assistant which view they wanted to see at certain times. Also, I directed the students more during this phase by asking questions on what they were thinking at
different intervals. As a result, I combined some of the Phase II categories and added new categories (Figure 62).

All interactions were tied back to the main category Using LAMRS, with subcategories related to either performing an injection or issues related to the LAMRS technology. Subcategories for performing an injection were anatomy and technique. These two categories are interrelated; an injection cannot be administered without consideration of both. Students spent time considering anatomy and technique separately and then verbalized understandings of each category and the correlation between the two.

**Examples of interactions for each category.** As mentioned, anatomy and the technique for performing injections are closely related. Using LAMRS, students were able to appreciate the anatomy and how it related to what they had learned and been told.

*Figure 62. Phase III matrix of relevant qualitative categories.*
didactically. Amanda asked that the 3D model be turned 360 degrees so that she could view the image from all angles. Looking at the anatomy from a first-person perspective in 3D seemed to drive a higher level of conceptual understanding for the anatomy. Students made comments that while they knew where the internal oblique ridge was located, they did not realize that the bone size changed so dramatically as it advanced upward. An understanding and acknowledgment of the anatomy of the internal oblique ridge was a benefit of using LAMRS.

Performing an injection: anatomy. A virtual environment seemed to allow students to understand spatial and dimensional relationships of cranial anatomy above that of traditional educational practices. Another benefit of LAMRS was the allowance of multiple views: oral, translucent, and bony. Below, Alyse communicates that the translucent view of the oral anatomy is helpful because she can see how the oral landmarks are superimposed over the bony landmarks and nerves. Alyse took her time in this view to understand what she was looking at. When Alyse finally attempts an IA injection, her attempt is good and inline with the nerves. Also below, Katie, who made an attempt at an injection, was viewing her attempt with the green stand-in changing through the different views. Katie was able to identify that her attempt was too low in the inverted triangle and angled too far to the molars, which would ensure a higher level of osseous contact.

Alyse: “I like the translucent view where I can see where the raphe is positioned over where the nerves are located.”
Katie: “I am too close to osseous, and too low in triangle.” We discuss the student’s attempt with the green stand-in to analyze penetration, depth, and targets. She has gone through the cheek, a dramatic angle assures a higher likelihood of osseous and if higher on triangle, less chance of osseous.

**Performing an injection: technique.** This second category, technique, differs from the first because students demonstrate a higher level of reflection in discussing their attempts as they relate to the anatomy and how they can alter their attempt for a more successful injection. The ability to take time and evaluate an attempt was another benefit of LAMRS. When working with a live patient, the student cannot sit and evaluate her attempt, considering the positive and negative aspects of her technique, in front of the patient. Being able to look at the green stand-in (which represents her attempt) with different views of the tissue and anatomy was a huge help to the students and allowed them to control which view they saw when they felt it would be most helpful. This type of just-in-time feedback was especially helpful to the students and allowed them to strategize—talk and think their way through—their next attempt. I also observed that student technique improved in their handling of the syringe and how quickly they got to their site of penetration and advanced to their site of deposition. At first, students were slower and even shaky, but by their third attempt they were move confident in their movements and did not take as long to complete an injection. Below, Jackie goes into detail on her injection attempt and how she would need to alter her technique to make sure she does not get osseous contact.
Jackie: “Wow, I just barely missed the internal oblique ridge.”

Me: “This is good, you don’t want osseous contact but want to stay close the inside of mandible.”

Jackie: “Oh, I want to try again”

Jackie: “So, I need to make sure that my syringe is over the premolars of the opposite arch, and I need to pay attention to this line here (she points with syringe) and go opposite of my finger (palpating the bony ridge landmark).”

Me: “Good, I like that you are staying parallel to the occlusal plane.”

Me: “You don’t want to be too low.”

Jackie: “So, am I too low?”

Me: “What do you think?”

Jackie: “I don’t know because I got dinged for being too high on one of my last attempts”

Me: “You want to err on the side of being higher than lower.”

Jackie: “Oh.”

The student views her attempt in different views.

She talks her through her next attempt

She makes another attempt

Her attempt is good, just a little too far to distal of premolars (close to molar)

**Performing an injection: epistemic shifts.** At times a student would demonstrate an understanding, or synthesis of information, that would produce an “aha” moment, referred to as an epistemic shift. Similar to other categories, epistemic shifts go a step
further in a demonstration of when that shift in understanding takes place. Below,

Crystal talks her way through understanding her injection and those considerations she
would need to cognizant of to have a successful attempt. Mary verbalizes her own
account of her attempt that is included in this category.

Crystal: “From what I can see, I probably
need to rotate downward a little bit
(move wrist down). “Perhaps, I
need to get a little higher so that I
am more in the top of the triangle.
“It looks like the tooth is down and
I need to come up higher a little
bit.”

Me: “Gravity will cause the local
anesthetic substance to drift to the
nerve, better to be higher on your
attempt than too low.”

Crystal: “So, I need to go higher.”

Me: “Yes, and you will have less
osseous contact going higher.”

Crystal: “Oh, if I penetrate that high, then I
won’t miss it.” “I can see how if I
angle it this way (toward canine)
then I will go right past bone and
then I can re-angle if I want to.”

Mary: “Wow, I just barely missed the
internal oblique ridge.”

Me: “That is good, you don’t want
osseous but want to stay close to
the inside of mandible.”

Mary: “Oh, I want to try again. So, I need
to make sure that my syringe is
over the premolars of the opposite

She tries another attempt and I
have to caution her about her
angle, she is going upward like a
PSA, make sure to be parallel with
the occlusal plane

Student analyzes injection attempt
in different views.

She talks her through her next
attempt.
arch, and I need to pay attention to this line here (she points with syringe) and go opposite of my finger (palpating the bony ridge landmark)."

Me:

“Good, I like that you are staying parallel to the occlusal plane.”

Mary:

She asks “so, am I too low” I say what do you think “I don’t know because I got dinged for being too high on one of my last attempts”

Me:

“You want to err on the side of being higher than lower.”

Mary:

She makes another attempt

“Oh” Her attempt is good, just a little too far to distal of premolars (close to molar)

**Issue with technology: norming.** Some of the verbiage observed in the qualitative analysis had to do with issues with technology and the process of getting used to LAMRS that I refer to as “norming.” The greatest benefit to norming was that students gained an appreciation for the dimensionality of the virtual world. The addition of audio feedback was something that the students enjoyed during norming. Below, Amanda expresses that she needs to see the entire 3D model from all angles to get a good feel for what she is doing and for gaining a greater understanding of the anatomy. Many students like Denae express how “weird” it was to initially use LAMRS.
Amanda: “Will you move the model around so that I can view my attempt from all angles?”

Student did not succeed with getting the ball in the bowl twice, she was too shallow initially so did not understand depth.

Denae: “This is so weird.”

Student goes through norming steps

I help student to get her bearings in virtual world. Student makes an attempt, going slow getting used to the world.

**Issues with technology: planned experiences.** Some of the issues with technology had to do with built-in instructional experiences. I had learner prompts built into LAMRS that helped the students to identify and visualize the landmarks that make up the inverted triangle. Students found this experience to be helpful. The inverted triangle is one of the most difficult things for students to visualize. Below, Anna, Lisa, and Elizabeth talk about their experiences with this built-in direction.

Anna: “Wow! I am surprised how perfectly the nerves are lined up for a perfect shot.”

Student makes an attempt and we analyze it with the tissue gone. We reapply the triangle in the bony view.

Lisa: “I always wondered what the inverted triangle meant.”

Me: “Did that help?”

Lisa: “Yeah, it really helped to see what it means. I think that I learned more about anatomy than technique.”
Elizabeth: “The green dot, K.”

Elizabeth: “The nerves are in the middle of the triangle.”

Elizabeth: “I can see why you want us to penetrate a little higher than the exact middle of the triangle. The middle seems too low in the inverted part of the triangle, less room for error.”

We review anatomical landmarks and the inverted triangle.

Student views her attempt from all views, surprised how the triangle really helped for a correct injection.

We discuss the anatomical landmarks again.

Issues with technology: unplanned experiences. Unfortunately, there were experiences that had to do with technology that were unplanned and detracted from the virtual experience. The left hand data glove was difficult to calibrate for each user, especially because the female students have such tiny hands. Students commented that it was difficult to get a feel for their left hand since the visual representation of it was about two inches off in most cases. Also, the left eye of the HMD would episodically lose its video feed. Therefore, students would comment that they could not see very well or that their vision seemed blurry. We would stop everything at this point and try to solve the problem, which students found frustrating and increased the length of time that they were spending on the experience. At other times, the trackers would freeze, which meant that the world was stagnant and the user would not be tracked. Again, we would have to stop what we were doing and troubleshoot the problem. These experiences were obviously unplanned and will be considered on the next redesign of the virtual system. One feature that students expressed would be nice was if they could still see the regular world with the virtual. These comments were made mostly because they wanted to get their bearings and felt that if they could see what was around them that would help. I am not sure that it
would. In Table 26, Emily expresses her frustration with the left eye on the HMD, and the fact that her left hand was not properly calibrated in the world. Also, the carpule of anesthetic was falling out of the syringe, which she couldn’t see, that made the syringe awkward to work with.

Emily: “I am just seeing a blue screen in both eyes.”
Emily: “My left finger is not in the correct location” in the world.

Looking at monitor, she is about 2 inches to the left of patients face.

The carpule of anesthetic is falling out of the syringe.

Tracking of Two Students

Kristin. I randomly choose to track Kristin. Her experience seemed to be typical of other students. On the pretest Kristin scored 83% (7.5); on the posttest she scored 72% (6.5). Kristin’s score went down after using LAMRS. On the posttreatment survey, Kristin indicated a level 5 (out of 5) for understanding how anatomical form dictates technique and a level 4 (out of 5) on how well she knew and could visualize landmarks. She correctly expressed reasons for the failure of an IA and stated that she could not easily reposition the syringe and see where she needed to go while using LAMRS.

Kristin indicated a level 4 (out of 5) for comfort for giving an injection but did not think that her skills improved after interfacing with LAMRS. She acknowledged that she was better able to visualize the syringe angulations that led to a successful injection after using LAMRS and could verbalize how penetration and depth related to the mandibular foramen. Kristin could explain the rationale for positioning at the premolars of the
opposite side of the mouth and indicated a level 7 (out of 10) for the technology being helpful. Further, Kristin responded that the 3D LAMRS image was realistic but that she was not able to manipulate the 3D image without problems. Kristin stated, “I had a hard time with the 3D image, maybe because the right eye was out.” She indicated that she did not feel that her skills improved after using LAMRS and recommends that students should have a “better orientation to the system.” In the end, Kristin recommended the use of LAMRS to subsequent classes of dental hygiene students because, “it is good to see the innervations.” Figures 63 and 64 exhibit Kristin’s attempts at injections using LAMRS. Kristin experienced greater success with her attempts on the right side than on the left.

Table 27 includes the expert notes using the WREB rubric related to Kristin’s

Figure 63. Kristin’s attempts at a right IA.
Figure 64. Kristin’s attempts at a left IA.

attempts for local anesthesia. Listed are the notations for pass or fail on Kristin’s attempts.

*Qualitative analysis of Kristin’s interface with LAMRS.* I showed the inverted triangle guides to Kristin and indicated that her site of penetration should be slightly higher than the midline of the triangle and slightly toward that raphe, as indicated by a green dot on the image. Kristin stated, “The green dot? Ok.” She then attempted an injection with the dot in place. Kristin viewed her attempt from all views and was surprised how the triangle really helped for a correct injection. Kristin said, “The nerves are in the middle of the triangle.” We discussed the anatomical landmarks again and Kristin remarked, “I can see why you want us to penetrate a little higher than the exact
Table 27

*Rubric Analysis for Kristin*

<table>
<thead>
<tr>
<th>Kristin</th>
<th>Right oral</th>
<th>Right bone</th>
<th>Left oral</th>
<th>Left bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Good, at premolars. Pass</td>
<td>Fabulous. Pass</td>
<td>Penetration really far medial, did not move to premolar. Fail</td>
<td>Low on triangle but would have worked if no osseous, angle to OP slightly off. Pass</td>
</tr>
<tr>
<td>2</td>
<td>Good. Pass</td>
<td>Going through cheek, at an angle to OP, too far to premolars. Fail</td>
<td>Great, higher and more toward pres. Pass</td>
<td>Great, higher and more toward pres and correct angle. Pass</td>
</tr>
<tr>
<td>3</td>
<td>Good. Pass</td>
<td>Good. Pass</td>
<td>Good, a little bit of an angle. Pass</td>
<td>Right on target with the nerves. Pass</td>
</tr>
</tbody>
</table>

*Note.* She struggled with second injection and was not going parallel with OP, but changed, I guess that in real life the movements before penetration are not important, but the final attempt. Pass rate 10/12 = 83%. Four times that the clinical and bony view were the same: 4 pass.

middle of the triangle. The middle seems too low in the inverted part of the triangle, less room for error.”

**Summary of Kristin’s experience.** Kristin performed better on her injections for the right side than on the left. On the left side, she tended to angle her syringe too low, going at angle. Kristin said she felt more confident performing injections after using LAMRS but did feel that LAMRS did not impact her performance. Kristin experienced some problems with the left eye when using the system but did think the viewing of anatomical structures was very helpful and the best part of the LAMRS experience.
Kristin recommended the use of LAMRS for future classes of dental hygiene students if they had a better orientation to the system.

**Elizabeth.** Again, the decision to track Elizabeth was random. On the pretest Elizabeth scored 67% (6); on the posttest she scored 100% (9). Elizabeth’s score went up after using LAMRS. On the posttreatment survey, Elizabeth indicated a level 5 (out of 5) for understanding how anatomical form dictates technique and a level 5 (out of 5) on how well she knew and could visualize landmarks. She correctly expressed reasons for the failure of an IA and stated that she could easily reposition the syringe and see where she needed to go when using LAMRS. Elizabeth indicated a level 4 (out of 5) for comfort for giving an injection and did think that her skills improved after interfacing with LAMRS. She verbalized that the greatest benefit of LAMRS was the “visualization of landmarks.” Elizabeth acknowledged that she was better able to visualize the syringe angulations that led to a successful injection after using LAMRS and could verbalize how penetration and depth related to the mandibular foramen. She could explain the rationale for positioning at the premolars of the opposite side of the mouth for an IA and indicated a level 9 (out of 10) for the technology being helpful. Elizabeth responded that the 3D LAMRS image was not realistic and that she was somewhat able to manipulate the 3D image without problems. She felt that her skills improved after using LAMRS and recommended that students should have a “better orientation to the system.” In the end, Elizabeth recommended the use of LAMRS to subsequent classes of dental hygiene students “at or before learning local anesthesia.” In Figures 65 and 66, Elizabeth’s attempts are graphed. On both sides Elizabeth struggled with staying parallel with the occlusal plane and was
Figure 65. Elizabeth’s attempts at a right IA.

Figure 66. Elizabeth’s attempts at a left IA.
less correct on the left side.

Table 28 includes expert notes using the WREB rubric related to Elizabeth’s attempts for local anesthesia. Listed are the notations for pass or fail on Elizabeth’s attempts.

**Qualitative analysis of Elizabeth’s interface with LAMRS.** Elizabeth attempted an injection and viewed her attempt. She said, “Oops, I am going through the cheek. I guess that I need to move more anterior to avoid the bone.” She tries again and her attempt looks good because she altered her technique. On further analysis, Elizabeth stated, “Oh, but I went at a little bit of an angle.” I stated that she was at a bit of an angle but was in the correct location; she tries again. She couldn’t use her left hand to palpate;

Table 28

**Rubric Analysis for Elizabeth**

<table>
<thead>
<tr>
<th>Elizabeth</th>
<th>Right oral</th>
<th>Right bone</th>
<th>Left oral</th>
<th>Left bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beautiful.</td>
<td>Great.</td>
<td>Penetrated right on top of bone.</td>
<td>Osseous.</td>
</tr>
<tr>
<td></td>
<td>Pass</td>
<td>Pass</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td></td>
<td>Pass</td>
<td>Pass</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>3</td>
<td>Good.</td>
<td>A little high and at an angle.</td>
<td>Too high and toward incisors.</td>
<td>Site of deposition too shallow.</td>
</tr>
<tr>
<td></td>
<td>Pass</td>
<td>Pass</td>
<td>Fail</td>
<td>Fail</td>
</tr>
</tbody>
</table>

*Note.* She kept hitting her finger with needle tip, this student is a good clinician, surprised at her attempts; however, she does struggle and does things quickly. Pass Rate 6/12 = 50%. Six times that the clinical and bony view were the same: 3 pass and 3 fail.
her attempt is off and actually lateral to coronoid process.

**Summary of Elizabeth’s experience.** Elizabeth seemed to perform about the same in her injection attempts on both sides of the mouth. The graph of her attempts demonstrates that she struggled with keeping her syringe parallel with the occlusal plane of the teeth. However, even with her consistent angulations, she managed to pass 50% of her injections. Elizabeth did not experience any technical difficulties with the system and felt that using LAMRS did impact her technique and increase her self-confidence. Elizabeth stated that using LAMRS would be a valuable experience for future classes of dental hygiene if integrated very early on in their course on local anesthesia.

**Follow-up Questions**

**Students.** After my students had graduated and had the opportunity to work clinically for six months, I sent out the following question via email: *How do you feel the virtual local anesthesia experience may or may not have helped you?* Out of the 20 students that participated in the research, only four responded to my email and one of those four had not found a job yet so still did not have any experience. Lis commented that working with LAMRS “helped very much” and that the experience would have been more valuable if it was instigated earlier in her education. Amanda commented that she really liked it but her hands were too small for the data glove. Her further comments were “It honestly helped me see a better vision of landmarks. I had a really hard time understanding landmarks because it seemed like every instructor saw them different. I felt that the virtual local anesthesia gave me clear nonsubjective base to go off of, even when considering the differences from patient to patient.” Jessica said, “I thought that it
was helpful. I think that it's a nice way to get a little more comfortable with injections before actually doing it on a person! You know you can't hurt anyone so you can really focus on where you're going and where your landmarks are. Hope that helps!” And last, Vicki stated, “I have not as yet had the opportunity to obtain employment as yet. I will be temping tomorrow. Sorry I can not be of much help at this time.”

**Experts.** I asked three expert dental clinicians who have a history of working with the local anesthesia competency exams (WREB) to answer the following question: *Do you feel it may or may not help a student to learn about the administration of local anesthesia in a virtual environment where a cranial image could be manipulated to show translucency and cranial anatomy? What would be the practical significance of such a virtual system?*

Hygienist Connie Sliwinski stated that while patients consented to the local anesthesia given on the board exam, it was still unethical to use live patients and inject local anesthesia solutions for this purpose. She is a believer in the test, but feels that using a simulator could have great benefits: lower cost, less time, and a better output metric.

Dr. Roger Grua thought there was definitely value in using simulations as an instructional adjunct; however, he really doubts that simulations will replace live experiences. There are just too many variables that are present in a live situation that provide examiners with information about competency that can’t be simulated. He also says, “I have spoken to some candidates where their exam experience is their first time completing a clinical task. I found this scary and would hate to say someone is
competent on a simulation when the student has not actually worked with a live patient.”

“We both know that you can do an injection wrong according to a textbook but it may still get the patient numb. We are just testing for recommended technique and do not check to make sure the patient actually gets numb.”

Dr. Carol Naylor likes the idea of using a simulation system to teach the techniques for local anesthesia and for student practice. She has seen firsthand how nervous students get when they do their first injection as well as how intimidating it is when they have to perform an injection in a testing situation. Dr. Naylor thinks that evaluating skills competency is important but that qualified faculty in an accredited dental or dental hygiene institution should be able to apply a rubric to student performance to make this assessment rather than put the students and the patients through a live patient competency exam with an outside agency. If a virtual simulator had the capability to produce results that can support competence, than she feels there could be real value in a system to determine competency before live patient treatment. As for simulated practice, she states, “you can never get too much practice.” Anything that increases the student’s motor skills while boosting confidence in performance is a plus.

Summary of Results

Support for research question one. Two different questions on the pre/posttest demonstrate that the students understood the identification of the site of penetration for an IA injection and could label the inside and outside walls of the inverted triangle better after their interactions with LAMRS. The majority of the students indicated at a level 4 or 5 that they felt they could visualize the anesthetic landmarks after use with LAMRS.
The analysis of Excel data showed that on average student accuracy was best on their first attempt at an IA injection on the right side of the mouth and most correct on the second attempt on the left side of the mouth. The utilization of time decreased for each attempt on both sides. Qualitative analysis of student interaction with LAMRS indicated that while students claimed to understand cranial anatomical structures and dimensional relationships, they exhibited multiple aha moments when they understood where bony landmarks were situated in relation to intraoral tissues. The 3D analysis of the cranial image was very helpful in understanding recommended technique especially depth of penetration (Figure 67).

*Figure 67. Outcomes that support research question one.*
Support for research question two. The pre/posttest questions did not reveal any difference in scores, so these concepts were understood prior to the testing situation. On the posttreatment survey, the majority of the students indicated that after using LAMRS, they understood that anatomical form dictated clinical technique and that they understood syringe angulations and the correlation to successful anesthetic technique. The qualitative analysis revealed a pattern, or nodes, of thinking. This pattern was broken down into categories that included performance and technology with further subgroups in each category. Analysis of interactions or comments in these categories support that students benefitted from the ability to see the 3D image from a 360-degree angle and could be manipulated to allow for multiple views. Student understanding of anatomical relationships improved while their technique did not change much. There were episodes of planned activity and emergent activity that were both positive and negative (Figure 68).

Support for research question three. Again, there was no difference in pre/posttest scores for this section. The majority of students indicated an increased level of confidence after using LAMRS and did feel that their technique improved after the experience. The expert analysis of student performance based on a rubric revealed that the average pass rate for technique was 62%. Upon follow-up, students indicated that their understanding of anatomy, based on their experience with LAMRS, has impacted their performance for administering local anesthesia in private practice. Conversations with expert dental examiners thought the idea of a local anesthesia simulation was valuable for practice but would not replace live patient competency exams (Figure 69).
Figure 68. Outcomes that support research question two.

**Phase III: Refinement - Discussion**

The purpose of my research was to determine if students were able to learn the technique for providing local anesthesia using a mixed-reality system that allows them to manipulate 3D objects in virtual space. My research subquestions were: In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity? Will students develop better understandings regarding the application of anatomical and technical concepts through iteration? Will students be able to demonstrate the proper technique and verbalize a level of confidence for administering
Figure 69. Outcomes that support research question three.

local anesthesia after using the mixed-reality system?

I have organized the discussion with the presentation of support per research question first and the impact on theoretical constructs, with a discussion of the serendipitous outcomes and tracked students next. Then, I present the outcomes of the technology design goals and discuss the strengths and weaknesses of the research as well as make recommendations for future practice. Last, I relate my research back to the literature and reinforcing theory as well as the impact on the profession of dentistry and instructional technology.

**Research Question One**

Research question one is, *In what ways does using 3D objects allow for a greater*
understanding of anatomical spatial and dimensional acuity?

The evidence suggests that students liked the various views with LAMRS that allowed them to gain a greater sense of anatomical spatial and dimensional relationships. Students could study the 3D image at 360 degrees from a first-person perspective and gain a greater appreciation for the anatomy and technique. Several times students indicated how amazing it was to see where the nerves were located under the tissue and that they actually lie in the middle of the inverted triangle.

Other ways that the students learned were through iterative practice and constructive feedback. Students were able to see the impact of their attempt, and then evaluate and make changes for their next attempt, which is a form of participatory learning or "learning by doing," a concept supported in the theoretical grounding for this research. I was available to answer questions immediately and provide feedback on an attempt and guide the student to discover errors in technique. Due to the built-in learner direction for the inverted triangle, more students understood where this triangle was located and could draw it on a picture of the oral cavity after using LAMRS.

Research Question Two

Research question two is, Will students develop better understandings regarding the application of anatomical and technical concepts through iteration?

Using LAMRS helped students to understand how anatomy dictates technique. Students indicated on the pre/posttest that they understood the correlation between anatomical form and recommended technique; however, they could not consistently demonstrate correct technique based on these concepts. After using LAMRS, the
majority of students indicated that they understood this concept better.

Students learned through iteration the necessary depth and angles that are needed to perform a correct IA injection. As such, students reported on the posttreatment survey that they understood and could visualize landmarks and could explain the rationale for recommended technique after using LAMRS. There was further evidence of iterative learning when the students demonstrated improved technique with less time utilization. Performing a more correct injection shows an understanding of the anatomy and how it relates to anesthetic technique. Overall, students found LAMRS helpful for learning anatomy more than with anything else. For those students who experienced technical difficulties, they had some trouble viewing the 3D image and understanding how to improve their technique.

**Research Question Three**

Research question three is, *Will students be able to demonstrate the proper technique and verbalize a level of confidence for administering local anesthesia after using the mixed-reality system?*

Students demonstrated their conceptual understandings of anatomy and technique by improving their performance and by verbalizing their conceptual process. In addition, students indicated that the use of LAMRS increased their level of self-confidence for performing injections. Before the use of LAMRS, students could express in theory the correct technique but would not immediately demonstrate this technique by their physical actions. However, through iteration, their technique improved and was more aligned with what they had memorized and knew was correct. Thus, the gap was bridged
between what the students had learned and what they were expected to perform in a clinical setting. Students experienced a high pass rate using the WREB rubric, which supports the idea that a virtual environment could be used for skills-based competency testing with further research. The student’s use of time to perform an injection decreased with use of the system, which provides some support for automation and self-controlled practice with LAMRS. Upon follow-up, students indicated that LAMRS did help them to understand anatomy better and hence impacted their performance in clinical practice. Experts saw value in using a simulation system for practice; however, experts were not ready to concede that there could be a substitute for live patient competency-based exams.

**Emergent Outcome**

The Friday after using LAMRS, students practiced injections on each other to ready themselves for their board exam. They came to me to ask for help because they claimed they still did not understand the inverted triangle, the anatomy of inferior oblique bone, and the 45-degree angles of PSA. I was surprised by this revelation because we had just used LAMRS and had gone over these concepts. I told them about my surprise and suggested we use LAMRS again. This time using LAMRS, students exclaimed with excitement that they did not get as much out of their initial experience with LAMRS compared to the second use. Now they really understood the triangle and saw why LAMRS was created the way it was. The students said they went through the motions with LAMRS as academic practice but they weren’t really relating to actual technique until it was provided at just the time that they were asking themselves these questions.
Another interesting interaction occurred during the data-gathering phase of the research when some of the students were talking about how confused they were while trying to understand the landmarks for the anesthetic block for the top jaw. LAMRS is not set up with learner direction or with deformation to allow students to retract the cheek, so the posterior superior alveolar injection (PSA) was not taught at this phase. However, since the students were engaged, I decided that we could still see anatomy and could discuss the PSA if they were interested. There are three 45-degree angles that needed to be completed to perform this injection. With LAMRS, the students were able to get a good sense of these angles and finally understand the recommended technique. Like the other episode discussed, I found this interaction to be extremely valuable because the learning took place when the students were interested. Also, the theory that VR allows students to gain perspective and make assessments and connections was supported (Bowman et al., 2005; Burdea & Coiffet, 2003; Shelton & Hedley, 2004).

**Emergent Discussion of the PSA Injection**

Amber: “You know what I don’t understand? The inward and upward and backward motions. It is so confusing.”

Me: “I know, which is why I would like to include the PSA in LAMRS but it is not set up for that injection at this time.”

“[Amber]: I guess that we can still use the 3D object to look at the anatomy even though we are not set up for the injection yet. Let’s complete this IA and then try taking a look.”

“[Me]: We take the time to practice the PSA injection using the 3D object. I am surprised at how nice it is to identify landmarks and try angles with syringe even though we don’t have a way to retract cheeks I explain the technique and the angles I can point at screen with syringe and angles to demonstrate technique I explain the difference between an infiltration and a
Holly: “So it (tip of the needle for a PSA) is clear up where you would put an infiltration, but higher?”

Michelle: “Yeah.”

Student wants to do a PSA on other side and works hard to get angles right. She is a little too angled from midline. I would be able to demonstrate and the student could practice better with built in grids or lines for help. Perhaps on the next iteration.

**Tracked Students**

The composite data of each student’s experience was different. With the comparison of pre/posttests, the posttreatment survey, and rubric and qualitative data, I found that the student self report was often not consistent with qualitative data. Other inconsistencies were present as well. For example, Kristin scored a lower score on her posttest score than on her pretest. She reported that LAMRS was helpful at a level 7 out of 10 and that she recommended it for future dental hygiene classes. However, she indicated that LAMRS did not help her improve her technique. In addition, she indicated that she did understand anatomy better and that the LAMRS 3D image was realistic and she really liked the three different views that allowed her to see the innervations and the bone as well as experience an epistemic shift in conceptual understandings of the inverted triangle. Her performed attempts with LAMRS were consistently good, with a success rate of 10/12 attempts with little error.

On the other hand, Elizabeth stated that the LAMRS 3D image was not realistic and that she could somewhat manipulate the environment; however, she found the system to be helpful on a level 9 out of 10, her skills improved with the experience, and she
recommended using LAMRS for future dental hygiene classes. Elizabeth’s pre/posttest scores went up, but her attempts were often riddled with error, with a success rate of 6/12. Her attempts were more correct on the right side and more angled on the left.

Technology Design Goals

The technological design goals of Phase III included the use of a new data glove for the left hand, a new stereo-optic HMD (which required a splitter and extra monitor), an additional tracker (this makes three), an updated version of VirTools software, imbedded audio feedback, an orientation sequence for users, a stainless steel hand-held syringe and extensive work done on system calibration.

The technological goals for Phase III were met; however, technical difficulties were still abundant. Students liked using LAMRS but were distracted by technical difficulties with the HMD and the data glove. The left hand data glove was difficult to calibrate and impeded user sense of presence. The left eye on the HMD would inconsistently lose the video feed. This would require that we stop periodically to try to fix the problem. The evaluation of “timed” attempts was marginally valuable at this stage of research.

Those technologic aspects that worked well were the inclusion of a green “stand-in” line that indicated the students’ attempt was a great improvement to the system. The use of quantitative data, exported to an Excel spreadsheet, to track needle tip collision site and syringe trajectory was valuable in considering accuracy and technique. The inclusion of audio feedback during the norming sequence was fun for the students and the stainless steel syringe held up better with repetitive use than the plastic syringe used in the last
phase. Also, the calibration on the system was greatly improved.

As mentioned earlier, artificial environments should meet three criteria: high levels of presence, interactivity, and autonomy (Bowman et al., 2005; Burdea & Coiffet, 2003; Winn & Windschitl, 2001). LAMRS met these criteria for the majority of the time. As mentioned, the levels of presence could be reduced during times of technical difficulties, but once solved, we could continue with the learning experience. The level of interactivity and autonomy was adequate at this phase and resulted in promising evidence to move forward with automating more of the student navigation at this stage.

**Strengths and Weaknesses**

The strength of my research was that it was done using a DBR framework that allowed for thoughtful design and careful reconsideration. My research and iterations took place over time and were carefully planned and enacted. One of the limitations to my research was the timeframe it took to solve technical issues. It was expected that technical issues would arise working with complex hardware and software; however, the level of frustration was time consuming and difficult at times.

Another strength of the research was the Excel data collected for each attempt because it represents an output metric that adds usability to the system. In this way, evaluators could assess technique for the entire attempt, not just the end result. While students verbalized that their technique improved due to a greater understanding of anatomy, evaluation of student use of LAMRS was not a good indicator of skills competency as skills competency exams are currently understood.

It was interesting to watch some students who were resistant to using LAMRS
and said they did just fine during peer-practice have aha moments when they could see the transparency and bony views. “Watch your angle, you are coming in at an upward angle.” “I think I better do a better job in real life.” The student evaluates her technique from multiple angles to see how close her needle is to the target zone from side and front of 3D image. “Very interesting, I can see more why angles are so important.” I discussed with the student that she would not have been able to go through this process on a live patient. Some other student comments that I felt related back to traditional teaching were: “I always wondered what the inverted triangle meant,” after which I asked, “Did that help?” The student responded with, “Yeah, it really helped to see what it means.”

**Recommendations**

My recommendations for the next iteration are to have the students practice both the IA and the PSA nerve block. Even though I have not yet added the modeling that would allow for the retraction of the cheek, the students still found the experience helpful to go over the different angles of the PSA. I just need to work with my developer to add in some learner direction so that they understand the complex angles for this injection. Also, I would now have an experimental and control group and track skill acquisition and performance for local anesthesia between groups. With this proposed experimental design, the WREB rubric can be more appropriately employed during the research.

One of the most consistent problems that I have seen with students when they perform an IA injection is that they do not stay parallel with the occlusal plane. The graphing of Excel data was helpful in visualizing this error. Perhaps in the next iteration
there should be a blue stand-in that indicates the correct attempt along with the green one indicating the student’s attempt. A view of correct injection technique while the student is evaluating her attempt would help her to see the dramatic difference in her angle and the correct angle.

In the future, I plan to have the students interface with LAMRS many times over a period of several weeks. This research design would allow for the collection of longitudinal data and provide me with more data about student interactions with the system once they were more familiar with it. I would use a two-group (experimental and control) experimental approach to evaluate if the experimental group experienced a higher or quicker level of motor skill acquisition for correct anesthetic technique in a clinical environment.

As recommended by several students, I would plan to introduce LAMRS earlier in the students’ education on anatomy and local anesthetic technique. Various students commented that it would have been helpful to gain a level of understanding about anatomy that LAMRS enables.

**Reforming Theory**

The students went through the process of reflecting on their experiences and translating those experiences into concepts as outlined by Kolb (1984) in my theoretical grounding. The opportunity for reflection in a simulation setting and the development of conceptual understandings was seen as a huge benefit of LAMRS. Students had opportunity for feedback within LAMRS with the green stand-in and learner prompts for anatomical landmarks as well as with opportunity to dialogue with me while they
interfaced with the system. There was some evidence of motor skills acquisition with the
decrease of time that each attempt at an injection took correlated with increased accuracy
in performance. Student movements became less awkward and more fluid.

Students indicated in their posttreatment survey that using LAMRS increased
their level of confidence for performing injections. A higher level of confidence is a
predicted outcome of enactive experience, which involves direct learning where students
participate in an activity within a real physical environment, examining the pattern of
outcomes they have directly experienced and generating conceptions and rules of
behavior (Peng, 2008; Wei, 2008). With self-efficacy, a person will not make the effort
to change if they do not believe there is a chance of success. Success depends on the
ability to visualize performance, perform, and recover from failures (Bandura, 1982).
Interface with LAMRS allowed the students to experience success and recover from
failures in a safe, educational environment. Further research would need to be done that
would support that the confidence gained in a virtual (simulation) environment can be
transferred to actual clinical practice. Additionally, those virtual environments that
enable enactive experience can help students gain a higher level of self-efficacy prior to
performing injections on live patients.

Summary of Discussion

I expected that students working with the mixed-reality system would develop
acuity for the anatomical spaces and dimensions of the human cranium and discover
iteratively how anatomy dictates local anesthetic technique. The evidence suggests that
students liked the various views that allowed them to gain a greater sense of anatomical
spatial and dimensional relationships. LAMRS was effective to teach anatomical relationships. Students were able to understand how anatomy dictates technique. Students demonstrated their conceptual understandings of anatomy and technique. Students indicated that the use of LAMRS increased their level of self-confidence for performing injections. While students verbalized that their technique improved due to a greater understanding of anatomy, evaluation of student use of LAMRS was not a good indicator of skills competency as skills competency exams are currently understood. Learning took place as evidenced by a higher posttest score; the difference between scores was considered statistically significant. As mentioned, these outcomes help to support the theoretical constructs related to motor skills acquisition, learning with VR, and self-efficacy, as outlined in Chapter II.

Phase III: Refinement - Summary

Even though students knew concepts related to anatomy and saw pictures in books, there was a higher level of understanding while viewing these anatomical features with LAMRS from a first-person perspective in the virtual world. Cognition was impacted; students had a greater understanding of anatomy, technique, and spatial and dimensional relationships and could be taught the task for administering anesthesia. These outcomes support Fitts and Posner’s (1967) three-step theory on motor skills acquisition as well as demonstrate the advantages of making assessments and connections as well as perceptions and understandings learning with VR (Bimber & Raskar, 2005; Winn & Windschitl, 2001).

Students were able to associate anatomical structures to recommended technique
and could identify and label those structures utilized as landmarks for the IA injection. With the association for oral structures, students were able to practice the task for administering local anesthesia. In this process, the steps for skills acquisition—cognition, association, and automation—were supported and the ability to participate in self-controlled practice as supported by VR allowed students to gain perspective and focus in their learning (Bowman et al., 2005; Burdea & Coiffet, 2003; Shelton & Hedley, 2004). Research outcomes contribute to the theory that learning with VR can enable motor skills acquisition specifically through the three-stage process of cognition, association, and automation and that through this process, students gained a greater level of self-efficacy for administering local anesthesia. Therefore, the findings of this research have the potential to contribute to and advance the theories of learning with VR as outlined in Chapter II as well as motor skills acquisition and self-efficacy.

Students can learn the skill to administer local anesthesia using an interface that allows for the manipulation of 3D objects in virtual space. Students understood anatomical spatial and dimensional relationships as well as developed greater conceptual understandings. Students experienced iterative learning via the physical manipulation of virtual anatomical 3D objects. The multiple sensory explorations of 3D virtual objects provided the sensory feedback to the student about their actions in relationship to other objects. The unique combination of affordances with LAMRS provided a higher level of cognition to drive conceptual change than that of more conventional methodologies. There needs to be continued research in the use of VR technologies in dentistry. The continuity of VR research will have a profound impact on dentistry as the profession
moves close to the use of virtual practice and away from practice on live patients.
CHAPTER VII

CONCLUSION OF LAMRS PROJECT

My goal was to develop an instructional intervention using mixed-reality technologies that drove conceptual learning of local anesthetic technique and anatomical spatial and dimensional relationships. My instructional intervention allowed for experiential learning with guided discovery and JIT information. There were built-in prompts that enhanced the learning of anatomical landmarks and created views that allowed for transparent viewing of the oral and skeletal anatomy. Students were able to learn iteratively attempting injections in the virtual world several times. Therefore, cognition was supported, students were able to associate landmarks with technique and then practice, and students had time to troubleshoot and direct their learning to attain a higher level of automation. These outcomes are aligned with my vision as outlined in Table 6.

As mentioned, the ability to perform local anesthesia is a critical clinical skill for a dental hygienist. The educational processes for learning this skill have been steeped in peer and live patient practice. The provision for a simulated experience that allows the student to practice their skills for performing local anesthesia has the potential to greatly impact learning concepts that students traditionally struggle with. This project started with the desire to solve the learning challenges that students face for local anesthesia. As such, the initial phase of research started with learning the basics of VR technologies, pedagogical practices for learning with VR environments, and the creation of an initial VR system.
Phase I: Exploration - Synthesis

Phase I outcomes included an increase in knowledge base on the components and design of VR systems that have been used in medicine as well as on the pedagogical practices utilized with VR systems. When I assessed this developed system with what I had intended, I found it lacking in almost all the areas that I wanted my VR system to possess. During this phase, I was able to redesign and establish what I wanted my students to learn and envision the design for my current system (Table 29).

Phase II: Proof of Concept and Phase III:

Refinement - Synthesis

For Phases II and III, the same research questions were applied; therefore, the description of these phases will be combined. Research question one is, *In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity?* The ability to see the three different views three dimensionally that were available with LAMRS was helpful for students to gain a greater sense of anatomical spatial and dimensional relationships. Students could study the 3D image at 360 degrees from a first-person perspective and gain a greater appreciation for the anatomy and technique. Study of the 3D image allowed students to see where the nerves were located under the tissue and that these nerves lie in the middle of the inverted triangle. The participatory nature of working with LAMRS provided a sounding board of sorts for students to verbalize their understandings, perform attempts for local anesthesia, and then evaluate their technique. Students would talk out loud and to themselves in an
Table 29

Outcomes Synthesis of All Three Phases

<table>
<thead>
<tr>
<th>Research objectives</th>
<th>Become familiar with VR technologies</th>
<th>What types of learning take place in VR environments</th>
<th>Create a VR system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Researched Internet, books, articles, websites and listservs</td>
<td>First-person perspective, iterative learning, motor skills learning, association</td>
<td>Used ARToolKit and Daz Studio, HMD, and webcam</td>
</tr>
<tr>
<td>Phase II and III</td>
<td>RQ1: In what ways does using 3D objects allow for a greater understanding of anatomical spatial and dimensional acuity?</td>
<td>RQ2: Will students develop better understandings regarding the application of anatomical and technical concepts through iteration?</td>
<td>RQ3: Will students demonstrate the proper technique and verbalize a level of confidence for administering local anesthesia after using the mixed-reality system?</td>
</tr>
<tr>
<td>Phase II</td>
<td>By evaluating 3D image from 360 degrees, first-person layers, views, motor skills</td>
<td>Built in prompts, epistemic shifts, iterative learning, increased coordination</td>
<td>Professed self-confidence, system errors, decreased opportunity for automation</td>
</tr>
<tr>
<td>Phase III</td>
<td>First person, 360 degree self-controlled practice, motor skills, constructivism, Excel data on correct technique and time utilization, cognition</td>
<td>Guided discovery, just-in-time learning, iterative learning, prompts, epistemic shifts, visualize landmarks and provide rationale, physical actions, association</td>
<td>Pass rate Excel data, decrease in time utilization, increase in self-confidence, improving performance, verbalize conceptual process, physical movements – more fluidity, automation</td>
</tr>
</tbody>
</table>
attempt to synthesize information and to formulate their own understandings. As mentioned, even though students thought they knew anatomy and technique they were continuously surprised during their experience. Thus, students developed a higher level of understanding viewing these anatomical features from a first-person perspective in the virtual world. Support for research question one was found in both Phase II and III and somewhat in Phase I because about the only thing students could do was view the 3D image from 360 degrees during this phase.

Research question two is, *Will students develop better understandings regarding the application of anatomical and technical concepts through iteration?* Using LAMRS students were able to associate anatomical landmarks and their locations with recommended injection technique. Built-in learner prompts were instrumental in driving conceptual change for the inverted triangle. Students verbalized that they did not really understand the inverted triangle and its relation to both anatomy and technique. After using LAMRS, students could locate and label the inverted triangle on a diagram and verbalize rational for its use as a critical landmark for the IA injection. Students took the time to learn iteratively through trial and error with their technique and began to demonstrate more fluid skills and increased coordination.

Research question three is, *Will students be able to demonstrate the proper technique and verbalize a level of confidence for administering local anesthesia after using the mixed-reality system?* Students demonstrated their understanding of anatomy and technique by improving their performance and verbalizing their conceptual process. Students now could verbally provide rationale for their technique as well as demonstrate
correct technique. In addition, students indicated that the use of LAMRS increased their level of self-confidence for performing injections. Through iteration, student technique improved and was more aligned with what they had memorized and knew was correct. There was an increase in the fluidity of student movements and a decrease in time utilization for each attempted injection. These outcomes provide some support for automation and self-controlled practice with LAMRS. Student experienced a high pass rate using the WREB rubric which support the idea that a virtual environment could be used for skills based competency testing with further research. Upon follow-up, students indicated that LAMRS did help them to understand anatomy better; this impacted their performance in clinical practice and experts saw value in using a simulation system for practice. However, experts were not ready to concede that there could be a substitute for live patient competency-based exams.

**Revisiting DBR and Contributions to Theory**

In Chapter III, I outlined the five characteristics that are considered necessary for good DBR. In the following paragraphs I describe how my DBR project met these characteristics.

*The central goals of designing an environment and developing theories of learning are intertwined.* In Chapters II and III, I discuss the theories that frame my research and then discuss my research questions and how they relate to the theory. Phase I allowed me to decide what I wanted to focus on and how I wanted to progress. Therefore, my methodologies and technical design were impacted by those theories and
goals.

*Development and research take place through continuous cycles of design, enactment, analysis and redesign.* I progressed thorough three phases during the LAMRS research and altered and improved both my research process as well as the technical components of LAMRS design. Each phase of my research and the DBR process has been documented.

*Research on design must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers.* My research outcomes have provided support for theories related to motor skills learning, learning with VR and self-efficacy. My theories are shareable and will impact other practitioners and educational designers in their use of VR for learning.

*Research must account for how designs function in authentic settings and focusing too on interactions that refine our understandings of the learning issues involved.* In Chapters IV, V, and VI, I discuss the process and outcomes with each phase of research as it related to research design and technological design. LAMRS was built to be utilized chairside in an actual dental operatory, an authentic setting for dental motor skills acquisition. Qualitative data was discussed that enlightened readers on the learning issues involved.

*Methods here should document and connect the processes of enactment and outcomes of interest.* Methods for each phase of research were enacted and documented. Further, data was analyzed for outcomes of interest and presented in Chapters IV, V, and VI. The experience near significant related to the improved technological design of
LAMRS and that dental hygiene students in the research environment benefitted from interaction with LAMRS. The experience distant relevance relates to contributing to motor skills acquisition and the three-stage theory of cognition, association, and then automation. Theories related to learning with VR were supported as well as issues related to self-efficacy (The Design-Based Research Collective, 2003, p. 5)

**Reinforcing Theory**

My goal was to create a system that improved student cognition, motor skills, and confidence for administering injections. These goals are the basis for the theoretical grounding that frames my research. Those theories are motor skills learning—specifically related to Fitts and Posner’s (1967) three-stage process, self-efficacy, and learning with VR.

**Motor skills learning.** The three-stage process outlined by Fitts and Posner (1967) for motor skills acquisition includes cognition, association, and automation. Because of problems with my initial concept for LAMRS in Phase I, the students were not able to progress through these three stages. Only cognition was enhanced because students were able to view a 3D image from 360 degrees. However, the image was noninteractive and was nonchangeable. As a result, necessary motor skills were not acquired and student cognition for the relationship between anatomy and technique was hampered. In order to contribute to motor skill learning theory, my system was altered to allow for a three-stage experience to support a higher level of cognition for anatomy and technique, opportunity for association, and automation. Therefore, for Phase II, a human magnetic tracking system was added instead of pattern-recognition to render a 3D image
that could be manipulated. For Phase III, an additional tracker was added to include reification of the left hand, and a new HMD was purchased to increase fidelity of the image and immersive experience. Quantitatively, the students decreased their time utilization for administering an injection as they practiced. Qualitatively, students developed more fluid motions and verbalized understanding of anatomy and technique. These outcomes are consistent with those predicted by Fitts and Posner’s three-stage theory as well as Schmidt and Lee’s (2005) commentary on motor skills learning.

The following are specifics of how the theory was advanced and improvements were made after each phase to advance the research of theory.

- **Phase I: Outcomes** demonstrate that motor skills learning does not take place when only cognition was enhanced.
  - Design enhancements: human magnetic trackers, improved 3D image, embedded learner direction, assessment rubric.

- **Phase II: Outcomes** support that motor skills learning is advanced when cognition and association are supported but not fully realized due to limited opportunity for automation.
  - Design enhancements: additional tracker, new HMD, higher degree of system calibration, addition of a “norming” sequence, collection of Excel data.

- **Phase III: Outcomes** support that motor skills learning does take place when three stages of motor skills acquisition, cognition, association, and automation are supported (see Table 30).
Table 30

*Reinforcing Theory*

<table>
<thead>
<tr>
<th></th>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor skills learning</td>
<td>Motor skills were not learned when three-stages of learning were not supported</td>
<td>Cognition supported but association was moderately experienced and automation was limited.</td>
<td>All three stages supported and motor skills improved. More fluid motion and decrease in time utilization</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>Because enactive experience was not supported, students did not gain a level of self-efficacy.</td>
<td>Students were excited about the possibilities and although there were problems with user presence, still felt that their technique improved and felt more confident about performing injections.</td>
<td>Students were able to experience first person, administering injections, thus acquiring enactive knowledge. Their learning and success contributed to their reported feelings for confidence and self-efficacy.</td>
</tr>
<tr>
<td>Learning with VR</td>
<td>Zero presence felt. Decreased interactivity and opportunity for cognition of anatomic structures.</td>
<td>Increased presence and interactivity. Opportunities were present for cognition and association to take place.</td>
<td>Higher levels of presence and interactivity. Opportunities for cognition, association and automation were present.</td>
</tr>
</tbody>
</table>
- Design enhancements (to be completed for Phase IV): addition of a blue line as an indicator of correct technique for students to compare to green line indicating student efforts, and the addition of the injection for the upper jaw.

**Self-efficacy.** Bandura (1982) stated that success depends on the ability to visualize performance, perform, and then recover from failures. As such, actually performing a task, first person, is an enactive experience that is a common source of self-efficacy. By Phase III, students were able to perform and practice injection attempts and make judgments that impacted their performance and technique. These students reported an increase in confidence and self-efficacy for administering injections. This practice was not possible during Phase I, but failures at this stage set the bar for improvements in tracking, image fidelity, and immersive presence in Phases II and III. Research outcomes support the theory that virtual enactive experience allows for confidence to build and for skills to develop (Peng, 2008).

The following are specifics of how the theory was advanced and improvements were made after each phase to advance the research of theory.

- Phase I: Students did not gain a level of self-efficacy because enactive experience was not supported.
  - Design enhancements: human magnetic tracking, improved 3D image, synthesis software, and built-in learner prompts.
- Phase II: Students could interact with the 3D image and practice their injection attempts. Students were excited about the possibilities and although
there were problems with user presence, still felt that their technique improved and felt more confident about performing injections.

- Design enhancements: additional tracker and data glove to reify left hand, new HMD for increased user presence, the collection of Excel data, and the presentation of a marker to indicate student attempt.

- Phase III: Students were able to experience, first person, administering injections, thus acquiring enactive knowledge. Their learning and success contributed to their reported feelings for confidence and self-efficacy. (see Table 30)

- Design enhancements (to be complete for Phase IV): plan to include a blue marker to indicate correct technique, and plan to include the injection for the upper jaw.

**Learning with VR.** As stated, learning in artificial environments is successful because students can cognitively construct knowledge for themselves as they interact with the environment and observe the consequences of their actions (Bowman et al., 2005; Burdea & Coiffet, 2003; Shelton & Hedley, 2004). In Phase I, students did not experience immersion with the VR system and did not combine information to construct their own knowledge for administering local anesthesia. Therefore, Phase II included the use of human magnetic trackers and improved 3D image as well as some built-in learner prompts to facilitate this process. Phase III included improvements to the system that increased user immersion, ease of use with LAMRS, and the ability to capture relevant data for analysis. As such, LAMRS was a virtual environment that allowed for a first-
person, complex spatial experience that supported the freedom to choose experiences and make mistakes. Further, LAMRS supported the development of better understandings for students using an interface that allowed for the manipulation of 3D objects in virtual space and furthered the concept of “learning while doing.” Last, artificial environments should meet three criteria: high levels of presence, interactivity, and autonomy (Bowman et al., 2005; Burdea & Coiffet, 2003; Winn & Windschitl, 2001). Phase I did not meet these criteria and Phase II had a moderate level of presence and interactivity but a limited autonomy. Phase III met all three levels of criteria for artificial environments.

The following are specifics of how the theory was advanced and improvements were made after each phase to advance the continued research of theory.

- **Phase I:** User presence was nonexistent. Due to the pattern-recognition rendering system there was decreased interactivity; however, it did provide some opportunity for cognition of anatomic structures.
  - Design enhancements: addition of human magnetic trackers, synthesis software (VirTools), better 3D image, and built-in learner prompts.

- **Phase II:** Due to the magnetic trackers, users experienced an increased sense of presence and interactivity with the 3D image. Due to the ability to view the image from different angles and layers and built-in learner prompts there were more opportunities for cognition and association.
  - Design enhancements: addition of additional tracker and data glove to reify left hand, better HMD, indicator marker for student attempts, and collection of Excel data.
Phase III: Because students could view their left hand and performed a task to orient to the virtual world, users experienced a higher level of presence and interactivity. Design enhancement provided more opportunities for cognition, association, and automation, which is a process for motor skills acquisition but also for enactive learning in virtual environments (see Table 30).

- Design enhancements (for Phase IV): add indicator for correct injection to be used as comparison for student attempts, the addition of upper jaw injection, and improved calibration for left hand.

Summary

The field of medicine has embraced the use of and educational application for VR technologies in learning. The field of dentistry is just catching up to medicine in the use of immersive systems to improve educational practices and patient care. My research has the potential to have a profound impact on dental and dental hygiene education as well as on those competency-based exams that are currently practiced on live patients. There is a history of using 3D objects using a 2D interface such as a console computer. The difficulties of moving these experiences to an HMD are many; however, the educational benefit is concomitantly great. It is my recommendation that this technology be embraced because the benefits can mete a large increase in conceptual competencies of complex cognitive relationships.

My purpose with my research was to demonstrate that learning could take place using a mixed-reality system. I considered it premature to research whether LAMRS was
superior to traditional practice until I had the opportunity to investigate what types of learning took place with an instructional intervention and artificial reality like LAMRS. At this point, the three stages of motor learning—cognition, association, and automation—are supported. However, automation could be more fully realized if students had the chance to interact with LAMRS for a longer time frame over multiple periods. With that said, the instructional intervention was successful. Students were able to understand anatomical spatial and dimensional relationships, an outcome that is huge according to my experience as a dental hygiene educator for ten years. Once students understand anatomical structure, it is easier to understand recommended technique for the performance of an injection. Students were able to think critically when faced with atypical anatomy after gaining a clear understanding of conceptual relationships. I found that enactive experience impacted the level of student self-confidence. A big part of successful clinical practice has to do with confidence and a clinician’s interactions with their patient. One positive experience can go a long way to promote continued confident practice.

I will continue to use DBR strategies to carry on my research using LAMRS. For my next iteration, I will include the programming to include the upper block injection to the LAMRS experience and continue to investigate learning with LAMRS until I can eliminate most of the technologic system errors that have been encountered in order to get a better understanding of the impact of LAMRS on student learning. It is my intent that I will eventually build a virtual system to teach clinical instrumentation in a mixed-reality environment. I see great value in using immersive environments for learning and
plan to continue to contribute to the field of VR research in the future.

Within this document, I provided a complete overview of my research on utilizing a mixed-reality system to teach techniques for administering local anesthesia. The research took 4 years and represents a body of work that supports the use of virtual systems to teach complex cognitive relationships as well as provide an environment for self-controlled practice. Two accomplishments were outlined: (a) the design and development of a mixed-reality system called LAMRS for the purposes of my created instructional intervention, and (b) the conduction of three phases of research to refine and define my objectives and purpose for learning with VR systems. I recommended strategies for developing an instructional intervention and knowledge base for VR technologies. I provided a chronology of my process to help others that follow me in my endeavor to understand the educational application of immersive environments. I recommended a DBR approach to situate thinking in a model of iteration and not in the model of a “one-time” approach. Working with technology, a researcher needs to establish a timeframe, quadruple it, and would then have a more realistic idea of how long it takes to pull everything—hardware, software, funding, and so forth—together.

Some critical questions to ask myself at this stage are: What more can I learn conducting continued research with LAMRS? How can I best disseminate my knowledge to my professional peers? How can I enable collaboration for VR technologies with other professionals? As I move forward, it will be important to continue to challenge myself and my understanding of the use of VR technologies for educational purposes. To quote Dewey, “while not all experience is education, all
education should be experiential” (Dewey, 1938).
REFERENCES


APPENDICES
Appendix A

Glossary of Terms
<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARToolKit</td>
<td>Freely available software found on the Internet at the University of Washington Human Interfaces Technologies website.</td>
</tr>
<tr>
<td>Firsthand Technologies, Inc.</td>
<td>The professional virtual reality development group that I hired to build the VR application that I created. The developer I worked with the most was Howard Rose.</td>
</tr>
<tr>
<td>Haptics</td>
<td>Of or relating to or proceeding from the sense of touch; &quot;haptic data&quot;; &quot;a tactile reflex.&quot;</td>
</tr>
<tr>
<td>Inferior Alveolar (IA) Nerve Block</td>
<td>Nerve block injection for the teeth of the bottom jaw. This injection is referred to as the “IA.”</td>
</tr>
<tr>
<td>Internal Oblique Ridge</td>
<td>A section of the bone that runs along the inside of the jaw and advance upward toward the joint. The section, or ridge of bone that advances upward is referred to as the internal oblique ridge and represents a landmark for performing an IA injection.</td>
</tr>
<tr>
<td>Inverted Triangle</td>
<td>Referral to an invisible, upside down triangle that is a landmark for the IA injection. The cheek side of the triangle is outlined by the internal oblique ridge with the inside of the triangle formed by the pterygomandibular raphe. The top of the inverted triangle is outlined by the maxillary tuberosity and the bottom by the mandibular retromolar pad.</td>
</tr>
<tr>
<td>Iteration</td>
<td>The act of repeating a process usually with the aim of approaching a desired goal or target or result.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>-----------------------------</td>
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<tr>
<td>LAMRS</td>
<td>An acronym for the virtual system that I created called: Local Anesthetic Mixed-Reality System.</td>
</tr>
<tr>
<td>Lower Wing of the Sphenoid</td>
<td>The bony flanges that descend from the upper wings of the sphenoid bone. The lower wings create the side walls of the soft palate and represents the inside wall of the pterygomandibular fossa.</td>
</tr>
<tr>
<td>Mandible</td>
<td>The bottom (or lower) jawbone.</td>
</tr>
<tr>
<td>Mandibular Foramen</td>
<td>The hole on the inside of the jaw bone through which the nerve (inferior alveolar nerve) enters to provide sensation to the bottom teeth.</td>
</tr>
<tr>
<td>Mandibular Retromolar Pad</td>
<td>The pad of gum tissue behind the second or third molar of the bottom teeth.</td>
</tr>
<tr>
<td>Maxilla</td>
<td>The top (or upper) jaw bone.</td>
</tr>
<tr>
<td>Maxillary Tuberosity</td>
<td>The pad of gum tissue behind the second or third molar of the top teeth.</td>
</tr>
<tr>
<td>Maya</td>
<td>3D animation software.</td>
</tr>
<tr>
<td>Occlusal Plane</td>
<td>The plane created by the occlusal surfaces of the upper and lower teeth when they meet.</td>
</tr>
<tr>
<td>Osseous Contact</td>
<td>The contact of bone (osseous) with the needle of a syringe.</td>
</tr>
<tr>
<td>Palpate</td>
<td>To examine, or otherwise explore, (usually an area or organ of the human body) by feeling it.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Pattern Recognition Rendering</td>
<td>A method of rendering a virtual image through computer recognition of a pattern that generates an output of a prescribed 3D object.</td>
</tr>
<tr>
<td>Premolars</td>
<td>Human teeth situated between the canine and the molars.</td>
</tr>
<tr>
<td>PSA</td>
<td>A nerve block injection for the top back teeth. The nerve targeted is the posterior superior alveolar nerve, referred to as the PSA.</td>
</tr>
<tr>
<td>Pterygomandibular Raphe</td>
<td>The soft tissue near the back of the mouth that starts at the retromolar pad behind the molar and advances upward toward the maxillary tuberosity. This raphe is a landmark for the IA injection and represents the inside wall of the inverted triangle. When a patient opens wide this raphe is stretched and looks almost tendon like.</td>
</tr>
<tr>
<td>Reification</td>
<td>Regarding something abstract as a material thing.</td>
</tr>
<tr>
<td>Render</td>
<td>To make visible in a virtual realm.</td>
</tr>
<tr>
<td>Syringe</td>
<td>A dental tool used to hold a cartridge of local anesthetic with a needle on the tip used to perform an injection to numb a patient.</td>
</tr>
<tr>
<td>VirTools</td>
<td>Software to develop graphic, interactive, real-time virtual experiences.</td>
</tr>
</tbody>
</table>
Appendix B

Guided Discovery with LAMRS
DIRECTED EXPERIENCE WITH LAMRS

1. Orientation

1.1. Simple Task Performance

1.1.1. Students will perform a simple task to orient themselves in the virtual world.

1.1.1.1. Does your view change in the virtual world as you move your head?
1.1.1.2. Do you feel like your hand/syringe moved in the direction that you intended?

2. Visual Acclimation

2.1. View the 3D virtual object of a normal human head and oral cavity.

2.1.1. What do you see?

2.2. Change view to a Translucent view

2.2.1. What do you see now?
2.2.2. How does this view help you?

2.3. Bony view

2.3.1. What do you see now?
2.3.2. Does this view help you?

3. Right Side Local Anesthetic Attempt

3.1. Local Anesthesia Performance Attempt

3.1.1. Complete an injection from insertion to site of deposition.
3.1.2. Key press for Green Stand-in line of attempt
3.1.3. Change student’s view to bony view so they can analyze their technique according to landmarks.

3.1.3.1. How do you think that you did?

3.1.3.2. Would you do anything different?

3.1.3.3. Tell me what you are thinking.

3.1.4. Allow student to take time and do what they want at this step, allow for multiple LA attempts

4. Provide some learner Direction

4.1. Identification of the Internal Oblique Ridge (all 3 views)

4.1.1. Can you identify the internal oblique ridge?

4.1.2. Do you find this prompt helpful?

4.2. Identification of the Pterygomandiular Raphe (in 2 views)

4.2.1. Can you identify the pteryogmandibular raphe?

4.2.2. In what way has this prompt helped you?

4.3. Identification of the Inverted Triangle (all 3 views)

4.3.1. Can you visualize the inverted triangle?

4.3.2. How about now?

4.3.3. Allow for discussion to take place about the triangle

4.3.4. How has this prompt helped you?

5. Left Side Local Anesthesia Performance Attempt

5.1. Complete an injection from insertion to site of deposition and stop.

5.2. Key press for Green line stand in to become present
5.3. Change the student’s view to the other views so that they can evaluate their technique.

5.3.1. How do you think you did?

5.3.2. Would you do anything different?

5.3.3. Tell me your thoughts.

5.4. Let student spend time doing multiple attempts and what they want

5.4.1. Has working with LAMRS helped you with your technique?

5.4.2. In what ways?

5.4.3. Would you recommend the use of a virtual system to learn to administer anesthetic?

5.4.4. How has LAMRS helped where lecture and clinic may not have?
Appendix C

Pre and Posttest
Multiple Choice/Short Answer

1. Which of the following landmarks are associated with an inferior alveolar injection? Circle all that are appropriate.
   a. Internal oblique ridge
   b. Jugal ridge
   c. Pterygomandibular raphe
   d. Buttress of the zygoma
   e. Mandibular foramen
   f. Mental foramen

2. Explain why you choose to eliminate any landmarks from your last answer.

3. Describe the relationship of your syringe needle to the mandibular foramen.

4. The mandibular canine incisor is planned for root debridement, select the injection necessary to provide complete anesthesia.
   a. nasopalatine
   b. posterior superior alveolar
   c. inferior alveolar
   d. long buccal
   e. mental

5. What injection would you perform to anesthetize #28?
6. Identify the injection site for the IA on the left side with an X in the correct spot.

7. In the picture above, outline the inverted triangle for the right IA and identify the buccal and lingual walls of the triangle.

8. Identify the technique error associated with this pictured of the IA injection.

9. How would you correct this technique?
Appendix D

Posttreatment Interview
Post Interview

1. On a scale from 1-5 (5 being the highest,) how well do you understand how anatomical form dictates techniques for anesthesia?

2. On a scale from 1-5 (5 being the highest), how well do you feel you know and can visualize the anatomical landmarks?

3. If anesthesia is not achieved with an IA, what could be the possible reasons for this failure? Why?

4. Were you able to see where and when to reposition the syringe / needle to get to the correct site of deposition?

5. On a scale of 1 – 5 (5 being very confident) how confident do you feel giving injections?

6. Did you find that your technique for anesthesia improved as you interfaced with the mixed-reality system? Why?

7. Were you more fully able to understand how proper syringe angulations leads to a successful injection?

8. Explain your understanding of depth of needle penetration as it relates to the mandibular foramen for the IA injection.

9. Explain the rationale for premolar positioning with the IA injection.

10. Was this technology helpful on a scale of 1-10 (10 being very helpful)?

11. In what way was the 3D image realistic or not realistic?

12. Were you able to manipulate the 3D image without any significant problems?

13. Do you feel your skills have improved from using this technology?

14. Do you have any suggestions for improvement on this technology?

15. Would you recommend this technology for future dental hygiene classes?

16. Overall, was this an effective experience?
Appendix E

WREB (Western Regional Examination Board)

Local Anesthesia Rubric
## ANESTHESIA CANDIDATE EVALUATION

Candidate #

The areas checked below were not performed at a passing level for the reasons noted. The areas marked with an * are reasons for failure. Errors marked in categories without an # are not reasons for failure, but are areas that need improvement.

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>1st IA</th>
<th>2nd IA</th>
<th>1st PSA</th>
<th>2nd PSA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. MEDICAL HISTORY, ANESTHETIC &amp; SYRINGE SELECTION</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><em>Contraindication - med history</em></td>
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<tr>
<td><em>Anesthetic inappropriate</em></td>
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<tr>
<td><em>Syringe incorrect</em></td>
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<tr>
<td>2. SYRINGE PREPARATION &amp; HANDLING</td>
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<tr>
<td><em>Incorrect armamentarium</em></td>
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<tr>
<td><em>Syringe improperly prepared</em></td>
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<tr>
<td><em>Contaminated needle</em></td>
<td></td>
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<tr>
<td><em>Syringe in patient’s sight</em></td>
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<tr>
<td><strong>3. PENETRATION SITE</strong></td>
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<tr>
<td><em>Contaminated needle</em></td>
<td></td>
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<td></td>
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<tr>
<td>3 Unsuccessful attempts to penetrate</td>
<td></td>
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<tr>
<td><em>Too superior</em></td>
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<tr>
<td><em>Too inferior</em></td>
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<tr>
<td><em>Too medial</em></td>
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<tr>
<td><em>Too lateral</em></td>
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<tr>
<td><strong>4. ANGLE &amp; DEPTH</strong></td>
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<tr>
<td><em>Barrel too distal</em></td>
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<td><em>Barrel too nasial</em></td>
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<tr>
<td><em>Angle too high</em></td>
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<tr>
<td><em>Angle too low</em></td>
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<tr>
<td><em>Too shallow</em></td>
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<tr>
<td><em>Too deep</em></td>
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<tr>
<td><strong>5. ASPIRATION</strong></td>
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<tr>
<td><em>Window not visible</em></td>
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<tr>
<td><em>No aspiration observed</em></td>
<td></td>
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<tr>
<td><em>Improper handling after positive aspiration</em></td>
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<tr>
<td><strong>6. AMOUNT AND RATE</strong></td>
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<tr>
<td><em>Too much anesthetic before aspiration</em></td>
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<tr>
<td><em>Too fast</em></td>
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<tr>
<td><em>Too slow</em></td>
<td></td>
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<tr>
<td><strong>7. SHARPS AND BIOHAZARDOUS WASTE HANDLING</strong></td>
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<tr>
<td><em>Improper recapping</em></td>
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<tr>
<td><em>Improper disposal</em></td>
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</tr>
</tbody>
</table>

1st INJECTION: ☐ PASS ☐ FAIL
2nd INJECTION: ☐ PASS ☐ FAIL
Appendix F

WSU IRB Approval Letter
January 12, 2009

Kami M. Hanson
3920 University Circle
Ogden, UT 84408-3920

Dear Kami:

Your project entitled "Utilizing Mixed-Reality Technology To Teach Techniques for Administering Oral Anesthesia" has received an "expedited" review and is approved.

We wish you good luck with your project and remind you that any anticipated changes to the project and approved procedures must be submitted to the IRB prior to implementation. Any unanticipated problems that arise during any stage of the project require a written report to the IRB and possible suspension of the project.

A final copy of your application will remain on file with the IRB records. If you need further assistance or have any questions, call me at x6841 or e-mail me at dkawamura@weber.edu.

Sincerely,

Diane M. Kawamura
Chair
Institutional Review Board
DCHP Sub-Committee
Title of Project: Utilizing Mixed-Reality Technology To Teach Techniques for Administering Oral Anesthesia

Primary Investigator(s): Kami M. Hanson

Approval Number: 08-HP-024

Reviewer: Diane M. Kawamura, PhD
Institutional Review Board

Date: January 12, 2009

COMMITTEE ACTION

Your proposal (project) and consent documents have been received and classified by the Human Subjects in Research Committee

AS:

High Risk  Moderate Risk  Low Risk

BY THE FOLLOWING PROCESS:

Full board review  Expedited review  Exemption

The project has been:

Approved  Not Approved

COMMENTS: See Attached Approval Letter

HUMAN SUBJECTS IN RESEARCH CHAIR  REVIEW DATE

INVESTIGATOR'S RESPONSIBILITY AFTER COMMITTEE ACTION

The federal regulations provide that after the committee has approved your study, you may not make any changes without prior committee approval except where necessary to eliminate apparent immediate hazards to the subjects. Further, you must report to the committee any changes that you make and any unanticipated problems involving risks to subjects or others that arise.
Appendix G

Reapproved IRB
December 17, 2009

Kami M. Hanson
Dental Hygiene
3905 University Circle
Ogden, UT 84408-3920

Dear Kami:

You submitted a request to have some minor changes to your study titled, *Use of a Mixed-Reality System to Teach Techniques for Local Anesthesia*, on December 8, 2009. According to your letter, these changes involved an addition of four questions. These questions are extremely low-risk, so the addition of these items is approved.

Please note that you will need to report any adverse events of your study to the IRB. Additionally, you would need to get approval for any further changes prior to data collection. We wish you the best with your project.

Sincerely,

Diane M. Kawamura
Chair
DCHP Subcommittee
Institutional Review Board

Letter written by: Dr. Theresa Kay
Chair
Weber State University
Institutional Review Board
Appendix H

Curriculum Vitae
KAMI HANSON  
Associate Professor

**EDUCATION**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Discipline</th>
<th>Degree Earned</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah State University</td>
<td>Instructional Technology</td>
<td>Ph.D.</td>
<td>2010 (May)</td>
</tr>
<tr>
<td>Weber State University</td>
<td>Education: Curriculum &amp; Instruction</td>
<td>M.Ed.</td>
<td>2004</td>
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<tr>
<td>Weber State University</td>
<td>Allied Health Administration</td>
<td>B.S.</td>
<td>1993</td>
</tr>
<tr>
<td>Weber State University</td>
<td>Dental Hygiene</td>
<td>A.S.</td>
<td>1988</td>
</tr>
</tbody>
</table>

**TEACHING**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Position &amp; Description</th>
<th>From - To (Mo &amp; Yr)</th>
</tr>
</thead>
</table>
| Weber State University| DENT 3305 – Concepts of Local Anesthesia  
DENT 4530 - Evidence Based Dental Hygiene Practice  
Experimental Project/Technological Initiatives  
DENT 4780 - Baccalaureate Thesis Course  
DENT 3336 & 3346/VA Medical Center Dental Clinic (Clinical Faculty) | Assistant Professor (FT) 2004 – Present 
*Assistant Professor Temp Hire* (FT) 2003 – 2004 |
| Weber State University| DENT 2205 - Head & Neck Anatomy  
<table>
<thead>
<tr>
<th>Institution</th>
<th>Courses</th>
<th>Instructor Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weber State University</strong></td>
<td>DENT 2205 - Head &amp; Neck Anatomy&lt;br&gt;DENSCI 3336 &amp; 3346/VA Medical Center Dental Clinic (Clinical Faculty)&lt;br&gt;DENT 3305 - Local Anesthesia Labs</td>
<td>Instructor (Adjunct Status) 2001 - 2002</td>
</tr>
<tr>
<td><strong>Weber State University</strong></td>
<td>DENT 2205 - Head &amp; Neck Anatomy&lt;br&gt;DENT 2250 - Professional Dental Ethics&lt;br&gt;DENT 3336 &amp; 3336/Dental Science Clinic Course&lt;br&gt;DENSCI 3336 &amp; 3346/VA Medical Center Dental Clinic (Clinical Faculty)</td>
<td>Instructor (PT) 2000 - 2001</td>
</tr>
<tr>
<td><strong>Lamar University Beaumont, TX</strong></td>
<td>General and Oral Pathology&lt;br&gt;Diet and Nutritional Analysis&lt;br&gt;Clinical Instruction: First &amp; Second Year Dental Science Clinic Course</td>
<td>Instructor 1992 - 1994</td>
</tr>
<tr>
<td>Title</td>
<td>Institution</td>
<td>Dates</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>DENT 3305: Concepts of Local Anesthesia</td>
<td>Weber State University</td>
<td>2007 - Present</td>
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<tr>
<td></td>
<td>Ogden, UT</td>
<td></td>
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<tr>
<td>DENT 4530: Evidence Based Dental Hygiene</td>
<td>Weber State University</td>
<td>2005 – Present</td>
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<td>Ogden, UT</td>
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<tr>
<td>DENT 4780: Baccalaureate Thesis</td>
<td>Weber State University</td>
<td>2005 – Present</td>
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<tr>
<td>Development and Writing</td>
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<tr>
<td>DENT 2205: Head &amp; Neck Anatomy</td>
<td>Weber State University</td>
<td>2000 – 2005</td>
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<td>Ogden, UT</td>
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<td>Health</td>
<td>Ogden, UT</td>
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<tr>
<td>DENT 3130: Independent Project</td>
<td>Weber State University</td>
<td>2003 – Scheduled as</td>
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<td></td>
<td>Ogden, UT</td>
<td>needed</td>
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<td></td>
<td>Ogden, UT</td>
<td></td>
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<tr>
<td>DENT 3336 &amp; 3346 &amp; 2236 &amp; 2246: Clinical</td>
<td>Weber State University</td>
<td>2000 – Present</td>
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<td>Instruction</td>
<td>Ogden, UT</td>
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<tr>
<td>General &amp; Oral Pathology</td>
<td>Lamar University</td>
<td>Beaumont, TX</td>
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<tr>
<td>--------------------------</td>
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</tr>
<tr>
<td>Clinical Instruction</td>
<td>Lamar University</td>
<td>Beaumont, TX</td>
</tr>
</tbody>
</table>

Development of teaching through travel, participation in conferences, workshops, seminars, short courses, etc.

2010

*STEMtech Conference.* Orlando, FL.

*Seventh Annual Faculty Forum.* Weber State University. Ogden, UT.

*TechExpo.* Weber State University. Ogden, UT.

*American Dental Hygienists Association Annual Session.* Las Vegas, NV.

2009


*American Dental Hygienists Association Annual Session.* Washington, D.C.

*First Annual Technology Symposium* hosted by Weber State University. Ogden.

2008

*The 16th Annual Medicine Meets Virtual Reality Conference.* Long Beach, CA.

*American Dental Educators Association Annual Session.* Dallas, TX.

*Association Educational Communications and Technology.* Orlando, FL.

*Conference on Information Technology.* SLC.

The New Media Consortium Conference on Mashups hosted by NMC. Second Life

2007

American Dental Hygienists Association Annual Session. New Orleans, LA.

American Dental Educators Association Annual Session. New Orleans, LA.

2006

Open Education Conference hosted by Center for Open and Sustainable Learning. Logan.

Utah Dental Hygienists Association’s Annual Session. SLC.

American Dental Educators Association’s Annual Session. Orlando, FL.

2005

American Dental Hygienists’ Association’s Annual Session. Las Vegas, NV.

American Dental Educators Association’s Annual Session. Baltimore, MD.

Dental Records Manager Plus hosted by Veteran’s Administration Hospital. SLC.

Utah Dental Hygienists Association’s Annual Session. SLC.

List evaluations, scholarships, awards, and other honors received in recognition of teaching.

- Award of Merit in Innovative Use of Technology & Mentoring
  Presented May 15, 2009 by Utah System of Higher Education

- Dumke Faculty Scholar Summer Stipend (2010 & 2008) $3,000 for publication

Teaching innovations and/or developments.

Redeveloped Course on Local Anesthesia DENT 3305
Description
Dr. Naylor and I team-teach the course on local anesthesia. We decided to throw out the old template and start fresh with our perspective on the class and what we wanted to get out of our students. The result is that we now have all motor skill related content at the beginning of the semester to give the students more time to practice their skills. Next, we added quizzes, or readiness assessments to the beginning of each class to give us an idea of what information the students understand and what information they seem to struggle with. This way we can customize each class to the student needs. We have integrated the “Clicker” system to enable immediate feedback from quizzes and so that students can gage where they are in their knowledge based compared to the group. Also, we now have student “hands-on” anesthesia labs directly after didactic class so that students can immediately embed content learned with first person enabled application.

Status
- Phase II: 2009 – the addition of Clickers
- Phase I: 2008 – major redevelopment of course

Teaching Outcome
- Daily readiness assessments
- Use of clickers
- Motor skills learning at beginning of semester
- Immediate “hands-on” labs

Redeveloped Course on Principles of Evidence Based Dental Hygiene Practice & Baccalaureate Thesis Writing DENT 4530 & 4780 (Fall 2009 & Spring 2010)

Description
When I was assigned this course, my first objective was to provide instruction that would make clear research questions, design and assessment. I had found that students didn’t see the need for the alignment of these components of research. Also, I found that the students needed direction on their writing skills, would benefit from the instigation of peer reviews and needed training on Excel to evaluate and provide visuals of their collected data. I developed a rubric for grading the research papers before I was assigned the course and have continued to utilize this rubric in the course. The use of Thesis Advisors for the students have had mixed results since the history of this course. Fall 2009, I developed comprehensive materials (ie: course syllabus, schedule, modules, list of assignments and a style guide) to provide to the Thesis Advisors to clarify roles and responsibilities as well as met with every advisor prior to
the start of the semester and as needed during the semester.

Teaching Outcome
- New Style Guide
- Support Materials for Thesis Advisors
- Meetings with Thesis Advisors
- Rubric
- Excel Training
- Peer Review Guidelines

Computer-Mediated-Communication (CMC) Initiatives

Description & Teaching Outcomes

a. Podcasting – I have been interested in the potential of podcasting because it resonates with my desire to make learning objects more mobile. I had wanted to pursue research with handheld devices like palm pilots, but the iPod came on so fast and strong and has really changed audio/video media. As a result, I have shifted my focus to learning objects that can be “podcast” using iPod-like technology. Fortunately, I have two groups of students now that are interested in investigating the use of podcasting as an educational project. During the fall 2006 the students and I created “podcasts” related to two core curriculum courses and made them available as a link on the student’s website. So far, the podcasts have been a huge success. The students (under my tutelage) are conducting research and collecting data during the spring 2007 semester to investigate the impact of podcasting on learning. This is a relatively new initiative so more evidence is pending. Plans have already been set in motion to continue with this initiative by creating podcasts for two other core curriculum courses to be utilized next year 2007-2008. In addition to podcasting, a new phenomenon has developed called “mashups.” A mashup is a compilation of a novel electronic work, usually with video and audio, created from previously existing work. I have worked with two groups of students in the development of mashups for educational purposes. We created a fun oral hygiene video from YouTube clips and selected music.

Teaching Outcome – The development of two podcasts on dental hygiene instrumentation and one oral hygiene mashup for educational purposes.

b. Blogs – I first started to use blogs in my course on Community Oral Health (2004) as a way for students to submit assignments so that other students could view their efforts and provide feedback. At the end of the semester, I realized that I had tapped into a valuable resource for learning, virtual communications and peer-to-peer learning. As a result, we have incorporated the use of blogs across the curriculum and have found it to be very beneficial.

Teaching Outcome – The initial integration of electronic blogging as an educational
Additionally, I encouraged the incorporation of blogs across the curriculum (2005-2006) to be used as appropriate for each course (Exhibit 39). In the clinical courses students have traditionally been required to keep a journal to reflect on their clinical experiences. However, the hardcopy journals did not enable a level of reflective thought but rather habitual action. It was hypothesized by myself and S Alexander (and researched to fruition) that students would make more of an effort in their journaling if their thoughts were available for peer review and commentary. Our research indicated that electronic (blog) journaling did support reflective learning and promoted emergent peer-to-peer learning and collegiality. As a result, the use of blogs for journaling has continued to present in the clinical courses.

**Teaching Outcome** – Students keep an electronic blog for their reflective journaling.

c. **VCoP** (Virtual Communities of Practice) - Since we have started a community of bloggers that have continued to interact with our educational community post-graduation, we wanted to investigate if our “community” interacted with quintessential dualities that are present in real communities of practice. In 2006, we utilized a rubric build by Lave and Wagner to evaluate for essential cosmopolitan qualities as well as dualities and incidences of reflective thought as posited by Mezirow. This research also led to further investigation into blog enabled peer-to-peer learning.

**Teaching Outcome** – The encouragement of blogging and Internet interaction in social networking systems that could support professional contacts and endeavors post-graduation.

d. **Wikis** – Fall 2005 during my course on Community Oral Health, I introduced the concept of wikis to the students as a way to interact somewhat like they did with blogs, but that with a wiki they could have a collaborative voice. The students had a great concern that wanted to collaboratively research and discuss in a protected environment that allowed for collaboratively collected and edited content. As a result, they started a password-protected wiki called “Get CHAPPed” for this purpose.

**Teaching Outcome** – The development of a password protected wiki for student collaborative use.

Due to the student’s familiarity of wikis, another professor in the dental hygiene program, F McConaughy chose to use a wiki for her course on periodontology during spring 2006. Wiki technology was more appropriate and worked better for her course due to the communal nature of the media rather than to utilized blogs. I continue to keep my eyes open for opportunities to use both types of CMC.

e. **WebCT** (now called Blackboard) – I took the classes to get certified as a designer and teacher with WebCT (Spring 2004). I think that WebCT has a lot to offer to educators as far as making content available and providing a safe, password protected
site for virtual communications. I have tried to be collegial in my support of getting
our entire department to utilize WebCT to enhance our students’ education.

**Teaching Outcome** – the continued use of Blackboard (formally WebCT) to provide
electronically delivered content to face-to-face students.

**f. Collaborative work in Website Design** – When websites were relatively novel and
Weber State did not provide hosting for students, my students and I conceived of a
project to create a student developed and maintained site for the dental hygiene
program (2003). In addition, the students wanted to experiment with putting our
clinical manual online for easier access and a quicker search for information. This was
a great project and we all learned a lot. The students and I presented in New York City
on this project at the American Dental Hygienists Associations annual session. I still
use website design as an educational strategy at this time.

**Teaching Outcome** – A reference website and a current usable student website with
similar content to what was originally envisioned but with links that include student
created podcasts.

**g. Student Portal Site** – This represents the second generation of the previous project
in website design. Weber State decided that they did not want groups or programs to
have their own sites, that everything should be consistent. So they now offer hosting to
students groups like ours so that students can now have a password protected site to
house all of their information. I worked with the students to develop their site as a
portal off of Weber’s site (2004 – present). Each year a student webmaster is selected
to work closely with me to provide a rich site to support student learning. This has
worked out beautifully as a way to share information and resources and promote virtual
interactivity among students.

**Teaching Outcome** – The development and utilization of a student “clubs” group page
that delivers content that is student driven.

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**The Research and Creation of a Solution to a Grading and Data Management
Problem**

- K Hanson

**Description**

In 2001, I identified a need for the department to improve its system for collecting
clinical materials to grade and to store this data gathered. As such, I conceived of an
initial idea to get funding through RS&PG to build an architectural framework on
which to build a custom designed database system. My idea was novel and not well
understood at that time and my funding was denied. I worked with on-campus support
to craft my own Access database program to solve our problems, but our needs in the
department required multiple, “many-to-many” relationships, that it was not possible to
solve simply with onsite training. At this time, proprietary programs did not exist that
could be retooled to meet our needs. Over the years, I have made other attempts at grant proposals and have been denied. I have worked with Craig Gundy and his ChiTester group and have not found a solution. I have used WebCT or Blackboard to its maximum capacity and have yet to find a viable option. Today, I am researching online proprietary data management programs to see if they can be retooled to fit our needs. The technology has gotten more sophisticated and available that we may see a solution in the near future.

**Status**

- Phase V: 2010 – Purchase and implementation of the program TalEval
- Phase IV: 2009 – Working with online Proprietary Programs to carve out a solution
- Phase III: 2006 – Pilot project with Gateway laptop computers and WebCT Initiated
- Phase II: 2004 – A Retooled Grant Proposal to RS&PG Denied
- Phase I: 2002 – Grant Proposal to RS&PG Denied

**Eventual Teaching Outcome**

- A password protected, online grade submission and data management system for student and faculty use.

**SCHOLARSHIP**

Published articles.

**Published**


**Submitted for Publication**


Unpublished manuscripts.


Addresses to professional groups.

2010


Hanson, K., Naylor, C., and Alexander, S. (2010). Virtual tools for a real education. *Seventh Annual Faculty Forum*. October: WSU. Ogden, UT.


2009

Hanson, K. (2009). Virtual reality and design-based research. *Sixth Annual Faculty Forum*. October. WSU. Ogden, UT.


2008


2007

Hanson, K. (2007). A pilot study: Utilization of a virtual reality system to teach techniques for local anesthesia. *Fourth Annual Faculty Forum* (October), Weber State University, Ogden, UT.

Hanson, K. and Alexander, S. (2007). The educational use of “mashups.” *Fourth Annual Faculty Forum* (October), Weber State University, Ogden, UT.

Hanson, K. (2007). The utilization of virtual reality to teach techniques for local anesthesia. *Third Annual Faculty Forum* (April), Weber State University, Ogden, UT.


Hanson, K., Carlile, J., Bowen, J. and Parcell, L. (2007). Emotional intelligence and
success in dental hygiene student clinical practice. *American Dental Educators Associations Annual Session*. Poster Session. New Orleans, LA.


2006


2005


Hanson, K. and Henson, S. (2005). Roundtable discussion on computer mediated communication and peer-to-peer learning. *Association for Educational Communications and Technology Annual Session*. Orlando, FL.


Research projects and grants.

*Weber State University’s Second Life Education Project: An investigation into Virtual Teaching, Learning and Research in Second Life*

- K Hanson (PI); Others: D Ferro, J Armstrong, B Johns, L Fernandez, B Ellis, S Rogers, G Niklason, A Lore, C Naylor, S Alexander
UR Students: K Hall, D Allen, P Carranza

Description
Second Life offers an accessible learning environment for participants regardless of their actual physical geographic constraints. Thus, accessibility is an especially appealing feature of SL for educators and geographically spread out communities of practice. In addition, SL offers a 3D virtual space within which participants can conduct enacted study of 3D objects from a first person perspective. Enactive experience, like constructivism, allows participants to “learn while doing,” encoding information into their schema iteratively. Our proposed research would investigate the presentation and learning of content and conceptual understandings in SL via scheduled presentations and 3D object lab study. Our broad guiding research questions are: what types of learning do students experience when using SL? Does learning in SL transfer to real life? And, do students perceive SL as instrumental in learning?

Status
- Phase II: 2010 - The Development and Implementation of a Large Second Life Education project, Specifically running a Dental Hygiene Board Review Session
- Phase I: Spring 2009 - Pilot Study in Dental Hygiene on the Complications and Concerns of Running a Real-time Educational Session in Second Life

Teaching Outcome
- A Second Life space in which to hold real time meetings or lecture courses.

Dissemination
Presentations – Please refer to Scholarship: Addresses to Professional Groups

Publication – Please refer to Scholarship: Publications

Funding
ARCC 2009 $6,916
Dumke 2009 SL letter $4,700
Marriott 2009 travel to present ADHA $ 2,485

The Utilization of Mixed-reality Technology to Teach Techniques for Administering Local Anesthesia
- K Hanson (PI); Others: A Lewis and Imprint Interactive, Inc.
- UR Students 2009: T Beckstrom, N Burghardt, and K Gibbons
- UR Students 2008: M Wright, A Allen, M Dahl and H Burton
- UR Students 2007: L Falselv, V Loesch and S Bates
- UR Students 2006: M Houghton, T Riley, B Stevens
- UR Students 2005: N Jones, M Krantz, H Law
Description
I have worked to research, develop and build an augmented-reality (AR) system that would allow my students to experience a 3 dimensional (3D) environment from a first-person perspective to learn techniques for administering local anesthetic injections. The impetus for this project arose from the apparent cognitive disconnect that I have seen students experience when they are asked to apply information learned in the classroom to a “hands-on” practical setting.

Status
- Phase III: Spring 2009 – Large research project on improved VR system.
- Phase II: Spring 2007 – Pilot research on the developed VR system.
- Phase I: Spring 2005 – The initial investigation and development of a VR system.

Teaching Outcome
- A VR system that can be used to teach students techniques for administering local anesthesia injections.
- A 3D interface that can be used to teach cranial anatomy and spatial relationships.

Dissemination
*Presentations – Please refer to Scholarship: Addresses to Professional Groups*
*Publication – Please refer Scholarship: Publications*

Funding
- Dumke 2008 $3,321
- Dumke 2007 $28,800
- Dumke 2005 $7,000
- Dumke 2005 $10,000
- Dumke Faculty Scholar Summer Stipend 2007 $3,000
- Dee Family Technology Award 2006 $3,400
- Marriott 2009 ADHA $2,485
- Marriott 2008 AECT $2,160
- Marriott 2008 ADEA $1,801
- Marriott 2007 ADHA $1,582
- Marriott 2007 MMVR $1,687
- Marriott 2006 ADEA $1,675
- Marriott 2005 ADEA $2,653
Emotional Intelligence and Success in Dental Hygiene Student Clinical Practice

- K Hanson (PI); Others: J Gall, K Johnson, M Olpin, S Bossenberger
- UR Students: J Carlile, L Parcell, J Bowen
- UR Students: J Figuera, T Bohman, K Blesse

Description
The purpose of this research was to investigate the impact of emotional intelligence (EI) on the clinical performance of dental hygiene students in patient treatment. It was hypothesized that a high EI score will correlate with a high score for student clinical performance in patient treatment. The guiding research questions were: 1) Does EI impact technical and interpersonal performance of student’s in the clinical dental hygiene treatment of patients? 2) Is there a correlation between and EI score and the ability to function in a stressful environment? And, 3) Could an EI score be used as a predictor of success? It is expected that there will be a strong correlation between an individual's EI score and their performance in the clinical dental hygiene treatment of a patient. Further, students are expected to perform better in a known environment, WSU Dental Hygiene clinic; than to perform under stress at the VA Hospital Dental Clinic. Those students who have a high EI score will perform better at the VA than those with a low EI score. (Exhibit 97)

Status
- Phase II: 2007 – Implementation of research.
- Phase I: 2006 – Securing funding for the MSCEIT test for emotional intelligence and the development of a research plan.

Teaching Outcome
- The awareness of emotional intelligence on student behaviors and application of knowledge learned in stressful situations.

Dissemination
Presentation – Please refer to Scholarship: Addresses to Professional Groups

Funding
- OUR Funding for MSCEIT Test
- OUR Funding for travel
- Marriott 2007 Funding for travel

Virtual Communities of Dental Hygiene Practice
**Description**
Since we have started a community of bloggers that have continued to interact with our educational community post-graduation, we wanted to investigate if our “community” interacted with quintessential dualities that are present in real communities of practice. We utilized a rubric build by Lave and Wagner to evaluate for essential cosmopolitan qualities as well as dualities and incidences of reflective thought as posited by Mezirow.

**Status**
- Completed 2006

**Teaching Outcome**
- The encouragement of blogging and Internet interaction in social networking systems that could support professional contacts and endeavors post-graduation.

**Dissemination**
*Presentation – Please refer to Scholarship: Addresses to Professional Groups*

*Publication – Please refer to Scholarship: Publications*

**Funding**
None

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### Blogging in a Course on Community Oral Health

- K Hanson (PI)
- UR Students: M Peterson, C Oberg

**Description**
The use of blogging was implemented in a course on community oral health concepts. The purpose was to engage students in using the Internet for research and data collection. With blog postings the students were able to interact and contribute to each others projects with resource sharing and supportive responses.

**Status**
- Completed 2005

**Teaching Outcome**
The initial integration of electronic blogging as an educational adjunct.

**Dissemination**
*Presentation – Please refer to Scholarship: Addresses to Professional Groups*

**Publication – Please refer Scholarship: Publications**

**Funding**
- Julie Snowball 2005 NMC Hawaii
- Marriott 2005 AECT $1,863
- Marriott 2005 ADHA $1,881
- Marriott 2005 ADEA Women’s Conf Montreal $3,246

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**Journaling and Reflective Practice**

- K Hanson (Co-PI) and S Alexander (PI)

**Description**
As part of a larger research project on virtual communities of dental hygiene practice, data was collected to evaluate, among other things, the level of reflective thought in blogging content. These outcomes were then compared to the level of reflective thought in hardcopy journaling to determine if one type of media supported a greater level of reflection than the other.

**Status**
- Completed 2007

**Teaching Outcome**
- Students keep an electronic blog for their reflective journaling.

**Dissemination**
*Presentation – Please refer to Scholarship: Addresses to Professional Groups*

**Publication – Please refer Scholarship: Publications**

**Funding**
- Marriott 2008 ADEA $1,801

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**The Practice of Selective Polishing in Dental Hygiene**

K Hanson
UR Students 2008: M Cameron, H Russell
UR Students 2007: A Demings, L Lackey
UR Students 2006: M Jones, M Rees, H Wilson

Project Description
Students are taught to practice “selective polishing” as benchmark practice during prophylactic procedures for dental hygiene. However, the concept of selective polishing is not widely practiced in a clinical setting. Current research has been conducted that dispels some of the initial concern about polishing enamel during a routine dental visit, however, the instruction of selective polishing continues in academia. Our purpose has been to open up a conversation again about selective polishing and challenge its continued relevancy in dental hygiene practice.

Status
- Phase III: 2008 – An investigation into the education of selective polishing in dental and dental hygiene schools across the nation.
- Phase II: 2007 – New methodologies were employed to get at the same hypothesis as the 2006 research.
- Phase I: 2006 – Students implemented methodologies to evaluate the surface of polished teeth to determine enamel loss.

Teaching Outcome
- The education and “selective” use of selective polishing.

The Investigation into the Efficacy of Plastic Surface Barriers in Dentistry
- K Hanson (PI)
- UR Students 2009 – C Chaffee, S Eggett, S Harrison
- UR Students 2008 – C Allred, C Baumgartner
- UR Students 2006 – M Myers, E Adams, D Nelson, A Butler
- UR Students 2004 – K Skeen, S Baza
- UR Students 2001 – P Morse

Description
Due to the increase and concern for communicable diseases, dentistry has responded with an increased use of plastic surface barriers as prophylactic measures. With the copious use of plastic surface barriers used in dentistry, our interest was to investigate the continued need for such practices. Are barriers truly helpful in cutting down on post-patient treatment and post-surface disinfection asepsis? The outcome has been that they are insignificant after the operatory is disinfected with OSHA approved surface disinfectants.

Status
- Phase V: 2009 – A meta-analysis of all existing research work for publication.
- Phase IV: 2008 – An investigation into the national use of barriers in dentistry.
- Phase III: 2006 – Implementation of seminal project research methodologies.
- Phase II: 2004 – Implementation of seminal project research methodologies.
- Phase I: 2001 – Seminal project on the efficacy of plastic surface barriers.

**Teaching Outcome**
- WSU dental hygiene program has greatly reduced their usage of plastic surface barriers on campus.

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**Infrared Technology: An Adjunctive Instructional Medium**

- K Hanson (Co-PI); Others: J Gall (PI)
- UR Students: C Gorringe

**Description**
The DeTecTar Device was developed to assist hygienists in the detection of subgingival calculus. Research has shown that it is an effective device for this purpose. As such, we developed a research project to utilize the DeTecTar as a clinical feedback mechanism to enhance student motor skills acquisition.

**Status**
- Complete 2005

**Teaching Outcome**
- The acquisition of DeTecTar units for clinical use

**Dissemination**
*Presentation – Please refer to Section IV: C and Exhibits 71 and 72.*

**Funding**
- Marriott 2004 Funding for DeTecTar units
- Funding from DeTecTar company in the donation of units
- Marriott 2005 ADEA $2,473
- OUR 2005 Funding for Student Travel to Present