

High Fidelity Virtual Environments:  
Does Shader Quality or Higher Polygon Count Models

Increase Presence and Learning

by

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## ABSTRACT

This research study investigated the effects of high fidelity graphics on both learning and presence, or the “sense of being there,” inside a Virtual Learning Environment (VLE). Four versions of a VLE on the subject of the element mercury were created, each with a different combination of high and low fidelity polygon models and high and low fidelity shaders. A total of 76 college age (18+ years of age) participants were randomly assigned to one of the four conditions. The participants interacted with the VLE and then completed several posttest measures on learning, presence, and attitudes towards the VLE experience. Demographic information was also collected, including age, computer gameplay experience, number of virtual environments interacted with, gender and time spent in this virtual environment. The data was analyzed as a 2 x 2 between subjects ANOVA.

The main effects of shader fidelity and polygon fidelity were both non-significant for both learning and all presence subscales inside the VLE. In addition, there was no significant interaction between shader fidelity and model fidelity. However, there were two significant results on the supplementary variables. First, gender was found to have a significant main effect on all the presence subscales. Females reported higher average levels of presence than their male counterparts. Second, gameplay hours, or the number of hours a participant played computer games per week, also had a significant main effect on participant score on the learning measure. The participants who reported playing 15+ hours of computer games per week, the highest amount of time in the variable, had the highest score as a group on the mercury learning measure while those participants that played 1-5 hours per week had the lowest scores.

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As I officially end my time in college and this chapter of my life, while moving on to bigger and better things, I'd like to quote Neal Peart of Rush in saying:

*Why try? I know why*

*The feeling inside me says it's time I was gone.*

*Clear head, new life ahead*

*I want to be king now not just one more pawn...*

## TABLE OF CONTENTS

	Page
LIST OF TABLES .....	vi
LIST OF FIGURES .....	vii
CHAPTER	
1 INTRODUCTION .....	1
Review of Literature .....	7
Virtual Environments for Training and Instruction .....	8
Presence and Learning in Virtual Environments .....	10
Situated Learning and Virtual Environments .....	11
Visual Fidelity as a Component of Situated Design .....	13
Visual Realism Research Studies .....	14
The Case for Higher Fidelity Visuals .....	15
The Case against Higher Fidelity Visuals .....	19
Visual Components of 3D Scenes .....	21
Polygons .....	22
Shaders .....	23
Summary of Research and Hypothesis .....	26
Research Questions .....	27
Variables .....	29
Measures .....	32
2 METHODS .....	36
Participants .....	36

CHAPTER	Page
Virtual Learning Environment Description.....	36
Content .....	37
Curriculum and Learning Objectives .....	38
Learning Area Descriptions .....	39
VLE Asset Creation .....	43
Game Engine and Hardware .....	44
Procedures .....	44
Pilot Study .....	44
Main Study .....	45
Scoring.....	47
Learning Measure .....	47
Presence Questionnaire .....	47
Reliability of Measuring Instruments: Pilot Implementation .....	47
Learning Measure Pilot Results.....	47
Presence Questionnaire Pilot Results .....	49
Presence Subscales Pilot Results .....	50
Sensory Fidelity .....	50
Involvement.....	51
Adaptation/Immersion .....	51
Interface Quality.....	51

CHAPTER	Page
3 RESULTS .....	52
Learning.....	52
Presence Subscales.....	53
Sensory Fidelity .....	54
Involvement.....	55
Adaptation/Immersion .....	57
Interface Quality.....	59
Supplemental Analysis.....	61
Gender and Presence.....	62
Sensory Fidelity .....	62
Involvement.....	62
Adaptation/Immersion .....	63
Interface Quality.....	63
Computer Gaming Experience .....	64
Time in Virtual Environment.....	65
Attitudinal Results.....	66
Interviews .....	69
4 DISCUSSION .....	73
Research Questions .....	73
Supplemental Variables .....	80
Attitudinal Discussion.....	81
Limitations.....	82

CHAPTER	Page
Future Research.....	83
Implications for the Field.....	84
REFERENCES.....	86
APPENDIX	
A COMMON ATTRIBUTES OF SHADERS .....	91
B DEMOGRAPHIC SURVEY .....	93
C PRESENCE QUESTIONNAIRE BASED OFF OF WITMER & SINGER’S PRESENCE QUESTIONNAIRE V 4.0.....	95
D LEARNING MEASURE ON SUBJECT OF MERCURY .....	99
E PARTICIPANT ATTITUDE SURVEY .....	104
F INTERVIEW QUESTIONS .....	107
G DESIGN DOCUMENT FOR VIRTUAL LEARNING ENVIRONMENT .....	109
H PILOT TEST QUESTIONNAIRRE .....	131
I LEARNING OBJECTIVES BY AREA.....	134
J IRB APPROVAL LETTER.....	138

## LIST OF TABLES

Table	Page
1. Factor Level by Condition.....	28
2. Means and Standard Deviations for Learner Score by Shader and Model Fidelity .....	52
3. Means and Standard Deviations for Sensory Fidelity by Shader and Model Fidelity .....	54
4. Means and Standard Deviations for Involvement by Shader and Model Fidelity .....	56
5. Means and Standard Deviations for Adaptation/Immersion by Shader and Model Fidelity.....	58
6. Means and Standard Deviations for Interface Quality by Shader and Model Fidelity .....	60
7. Means and Standard Deviations for Learner Score by Hours Playing Computer Games per Week. ....	64
8. Means and Standard Deviations for Time in Virtual Environment by condition.....	65
9. Means and Standard Deviations for Attitudes towards the VLE by Gender.....	66
10. Means and Standard Deviations for Attitudes towards the VLE by Age.....	68
10. Combined Mean Scores for Shader Fidelity on Presence Subscales.....	74
11. Combined Mean Scores for Model Fidelity on Presence Subscales .....	76



## LIST OF FIGURES

Figure	Page
1. Render of a Soda Can With and Without Shaders Applied to Model.....	4
2. Gameplay Point of View in a First Person Shooter (FPS).....	6
3. Screenshots from <i>Call of Duty 3</i> (2006) and <i>Crysis 3</i> (2013) .....	7
4. Difference in Image Clarity Due to Texture Size. ....	19
5. Polygon Components.....	23
6. Surface Roundness Differences between a Low and High Polygonal Mesh. ....	23
7. Examples of Procedural Textures and Standard Texture Maps .....	24
8. Render Comparison of a Shader in Development.....	25
9. The Four Rendering Conditions. ....	27
10. Entryway of the VLE Showing Some of the Exhibits.....	37
11. Partial Layout of the <i>Properties of Mercury</i> Area. ....	39
12. Partial Layout of the <i>Mercury In Our Everyday Lives</i> Area .....	40
13. Partial Layout of the <i>Dangers of Mercury</i> Area .....	41
14. Partial Layout of <i>How Mercury is Mined</i> Area.....	41
15. Partial Layout of the <i>Mercury Through the Ages</i> Exhibit .....	42
16. Partial Layout of the <i>Mercury and the Oceans</i> Exhibit .....	43
17. Estimated Marginal Means of Shader and Model Fidelity on Learner Score.....	53
18. Estimated Marginal Means of Shader and Model Fidelity on Sensory Fidelity.....	55

Figure	Page
19. Estimated Marginal Means of Shader and Model Fidelity on Involvement .....	57
20. Estimated Marginal Means of Shader and Model Fidelity on Adaptation/Immersion.....	59
21. Estimated Marginal Means of Shader and Model Fidelity on Interface Quality.....	61
22. Smoothing Group Effect on Model Surface.....	77

## CHAPTER 1

### INTRODUCTION

Virtual Environments (VEs) are a flexible medium that can be used for both training of job skills in the workplace and for teaching and learning within the classroom. The effectiveness of a VE as a medium for training, teaching, and learning is influenced by many factors outside of the VE space itself, such as the abilities of the learner or the design of the learning materials. Those aside, presence, or the user's sensation of "being there" in a virtual world is an essential component of the VE experience that may contribute to learning.

Many studies have sought to identify factors that influence user presence in VEs. Several factors, such as the use of audio to create ambient noise in the environment (Serafin, 2004), the use of sound for user interaction feedback (Whitelock, 2000), locomotion or the mechanics of moving inside the VE (Usoh, et al. 1999), and association with the virtual environment's avatar (Mikropoulos and Strouboulis, 2004; Slater et. al., 1995) have been studied, showing a consensus that all these factors positively influence the user's sense of presence in a VE. One design factor that has been less frequently examined and would intuitively seem to be one of the most important factors influencing user presence in a visually based medium is visual fidelity. Visual fidelity, and in particular a high visual fidelity, has a mixed empirical record in terms of its role in adding to a user's sense of presence. For every study that demonstrates a connection between higher visual fidelity and increased presence and/or learning in virtual environments, there is a study that contradicts those findings.

Visual fidelity in a VE is comprised of many different but associated components. The methods of handling lighting and shadows, the smoothness of the visual playback or refresh rate of the graphics, the surfacing of 3D models embedded in the VE, and the polygon count of the models all contribute to visual fidelity. The aim of the current study is to investigate the extent to which (1) the surfacing of 3D models using sophisticated shading networks and (2) use of high polygon count models positively affect user presence and learning inside a VE.

Presence can be defined as, "...the extent to which participants in a VE respond to virtual objects and events as if these were real." (Khanna, et al., 2006). Presence is important in any VE, but takes on additional importance with VE's being used for training or learning because, "...it has been argued that the tasks become more authentic and better training outcomes can be realized." (Whitelock, et al., 2000) Part of the authenticity is having the 3D models used in the simulation or VE look as close visually as possible when compared to their real world counterparts. This level of visual fidelity requires both having the physical shape of the models be accurate, and having the surface or surfaces of the models look as they do in the real world.

"Geometric realism" (Khanna, et al., 2006), which refers to "the level of detail at which environments are displayed," has been addressed in previous studies on presence. However, the actual geometry of the 3D mesh was not specifically investigated. Rather, the model's geometry was a single component contributing to the overall geometric realism of the 3D scenes used in the studies. One study by Cho, Park, Kim, Hong, Han and Lee (2003) did specifically address the impact of the geometric fidelity of a 3D model on presence. In the study, the geometry of the model was found to have little

impact on a presence, 9.14 on a scale of 0-100, where 100 meant that the participant felt completely in the environment. So the geometric shape of the model contributed less than 10% to the participant's sense of presence.

At the same time, however, the number of polygons that can be used to articulate a 3D model's shape continues to increase due to higher performing display hardware. This performance increase allows content creators today to create and deploy extremely detailed 3D models for VEs, even versus those which were created just two years ago let alone five or more years ago. Consequently, the value of highly realistic objects in promoting presence in virtual environments can more easily be studied, and remains an open research question.

It is not surprising that there are not many studies that focus only on the impact of geometric fidelity on presence because for a 3D model to look like a real world counterpart, there needs to be a combination of a 3D polygonal mesh, to give the 3D model its shape and form, and a shader to give the model its surface properties, like color, shininess, and roughness. Without the shader, a model will lose most of its visual detail, like in the following example (figure 1) of a soda can.



*Figure 1.* Render of a soda can with and without shaders applied to model.

Shaders are added to 3D models in order to give the polygonal objects the appearance that they are made out of some real world (or sometimes otherworldly material). Shaders define, “...how the ambient, diffuse and specular components of a material blend together.” (Gerhard, et. al., p. 400, 2010). Use of high quality shaders in VEs does not receive a lot of focus in the creation of VEs, particularly in VEs designed for training and/or educational purposes. Content creators and instructional designers frequently do not focus on creating shaders that manipulate all of the attributes that make a 3D model’s surface look like the real world surface of that object. A 3D mesh that has

one texture map applied to the color attribute may on first glance give that 3D mesh the appearance that it is made out a real-world material (e.g. wood or metal). But on closer inspection, the user will see that the surface of the 3D mesh looks wrong. The light does not bounce off the surface correctly, there are no reflections when maybe there normally would be or the surface looks too smooth. This lack of attention to shaders on 3D models gives the whole virtual environment an unreal appearance and may ruin the “suspension of disbelief” that allows the learner to believe they are actually present inside the VE. In other words, their sense of presence in the virtual environment is lessened. To illustrate the impact that both geometry and shaders have on perceived realism, the next section compares the current generation version of a popular commercial virtual environment-based game against a previous generation version of a similar game.

The *Call of Duty* series of games puts you, as a player, in the role of a soldier during battles that range from World War II to present day. The genre of game that *Call of Duty* falls under is a first person shooter (FPS). During gameplay, you see various battles from a first-person point of view in the battlefield (see Figure 2). The goal of the game is to complete mission objectives in order to defeat the enemy (Nazis, terrorists, rogue Russians, etc.).



Figure 2. Gameplay point of view in a first person shooter (FPS). Image from *Call of Duty: Modern Warfare* © Activision

Compare the images in Figure 3. These screenshots are from two titles released a few years apart. The one on the left is from *Call of Duty 3*, released in 2006. You can see clear, straight edges around the rounded surfaces of objects such as the helmet and a lack of articulated fingers in the hands. Furthermore, the blurriness of the textures is very noticeable on the rank insignias on the soldier's arms and on his pants. The blurriness is caused by having to use small texture sizes with the models to accommodate the limitations of the computer graphics cards and CPUs available in 2006. Finally take note of how the surfaces of different objects have roughly the same reaction to light. There does not seem to be a difference in how the uniform, the helmet and skin are illuminated even though one surface is cloth, one is metal and the other made of organic material. The image on the right is from *Crysis 3*, released in 2013). In this image, notice how the surfaces of the models look truly round due to the higher



number of polygons being used. The shaders are more robust allowing for specular highlights on the character's skin and the bullets visible in the magazines while the camouflage uniform retains a matte finish. Comparing these two images with regards to visual fidelity, the one on the left is low fidelity; the one on the right is high. If you placed a learner in a 3D virtual environment where the models and shaders were both manipulated to appear functionally realistic, it is reasonable to hypothesize that such a high visual fidelity environment would support a greater sense of learner presence, which in turn could foster better learning. This hypothesis is the focus of the current study. The following section provides an overview of the theory and design literature related to the core areas of the study: presence, learning and fidelity in virtual environments.



*Figure 3. Screenshots from Call of Duty 3 (2006) © Activision and Crysis 3 (2013) © Activision*

## **Review of Literature**

To preface a more in-depth discussion about the literature related to visual fidelity and its impact on presence and learning in virtual environments, it is useful to define what a virtual environment (VE) is and describe some of the benefits of using a VE for

learning. A virtual environment is a computer-generated, three-dimensional representation of a setting in which the users of the technology perceive themselves to be and within which interactions and activities take place (Dictionary.com, 2011). An Educational Virtual Environment (EVE) or Virtual Learning Environment (VLE) is basically the same as a virtual environment that "...has one or more educational objectives, pedagogical metaphors, provides users with experiences they would otherwise not be able to experience in the physical world and leads to the attainment of specific learning outcomes. (Mikropoulos, 2006). Why use a Virtual Environment (VE) for educational purposes or training? What are the benefits?

### **Virtual Environments for Training and Instruction**

There are numerous benefits to using a VE or VLE for either educational or training purposes. With regards to training, two of the primary benefits are safety and cost. Brooks, Jr., (1999) states in the context of training jumbo jet pilots that "...simulators, though costly, are much cheaper than airplanes. Much more important, pilots can train and exercise in extreme situations and emergency procedures were real practice would imperil lives." With regard to cost, Brooks also mentions that "scenarios can readily be run, accelerated, and switched, enabling more significant experience time per hour of training." Muchinsky (1999) concurs on these two benefits saying that "...transfer effectiveness ratio (TER) measures the ratio of time saved in real-world training as a function of time spent in simulator training. This TER ratio can be used to determine the cost-effectiveness of specific types of training compared to others, a value referred to as the transfer cost ratio (TCR). If real world training is not possible, then the

TCR will approach infinity - a clear reflection of the advantage of training in the simulated world.”

As with VEs as training environments, there are benefits to using VEs in an education setting. Some of the benefits are the same as those mentioned previously: safety and cost, but another benefit is increased learner motivation and engagement. Regia, Shebilske & Monk (1992) contend that if learning can be made more interesting and fun, students may remain engaged for longer periods of time. Virtual environments have the potential to engage learners in creative interactive tasks that could not be achieved through any other medium (as cited in Jelfs & Whitelock, 2000, p. 148). Motivation and engagement lead to the learner “...be(ing) present and active in their own learning” (Lim, 2006; Limniou, Roberts and Papadopoulos, 2008). Imagine taking a mini-submarine under the ocean, to explore the North Atlantic Ridge (Whitelock, et al., 2000), going into outer space without the astronaut training (Barab, Hay, Barnett, & Keating, 2000) or even going into inner space, observing chemical reactions (Trindale, Fiolhais,& Almeida, 2002) from inside a molecule. VEs allow for these kinds of experiences.

Yet motivation and engagement of the learner is of no use in a learning environment if the student does not actually learn anything in that setting. Virtual learning environments have been shown, in several studies, to increase learning in participants versus traditional classroom delivery. For example, Winn (2006) found that students who learned about oceanography (measuring, instruments, etc.) from a VLE scored as well as those students who went on location to a ship to perform the same functions. In addition, the students who used the VLE scored better than those on location about knowledge learned in class. Limniou, et al. (2008) reported that students

who used a VE projection technology called a CAVE to study chemistry felt that “the chemical reactions were more perceptible by using CAVE because they felt they were inside the molecules. Chau, Wong, Wang, Lai, Chan, Li, Chu, Chan and Sung (2011) tested whether a 3D virtual environment, *Second Life*, plus a classroom lecture could improve understanding of computer information security versus a lecture and a video covering the same topics. They reported that the students using *Second Life* had significantly higher overall perceived learning outcomes and also had higher test scores (5.97 versus 2.49) than those students using video. The authors suggest that “the learning process is significantly improved using the virtual environment as a learning platform instead of traditional learning methods like video.” Cheng and Wang (2011) conducted a study on whether using a 3D virtual environment would improve business students’ application of marketing theory. The results indicated that “the VLE did make a great contribution on facilitating students’ knowledge application ability” or using a (VLE) improved students’ application performance better than traditional teaching techniques.”

### **Presence and Learning in Virtual Environments**

The feeling of being “inside” a molecule or any other location while in a virtual environment is due to a phenomenon called “presence.” Presence can be thought of as, “...the subjective experience of being in one place or environment, even when one is physically situate(ed) in another” (Witmer and Singer, 1998). But how does the feeling of one being inside another space or reality affect learning or training? What are the implications and benefits of having higher presence inside an educational VE?

According to Mantovani & Castelnuovo (2003), the sense of presence makes the learning experience engaging and relevant, and a sense of presence helps trainees to

experience thoughts, emotions and behaviors similar to those they could experience in a real life situation. They state that the higher the user's sense of presence during the experience, the higher their emotional involvement, and the higher possibility of recalling the training situation. In addition, the sense of presence experienced by learners in Virtual Environment training can be thus considered as a key feature to ensure the efficacy of virtual training. Mikropoulos (2005) concludes that the sense of personal presence inside an educational virtual environment (EVE) help(s) learners successfully perform their learning tasks.

### **Situated Learning and Virtual Environments**

Situated learning is roughly "learning by doing in context." "This learning by doing is also focusing on real problems, or there is a very clear defined context to the problem in which learning is to occur."

([http://otec.uoregon.edu/learning\\_theory.htm#Constructivism](http://otec.uoregon.edu/learning_theory.htm#Constructivism)). Virtual environments let the designer put knowledge or information in the context of the situation or environment in which it would be used. This situated learning is typically much different from that of classroom learning in which the knowledge is presented outside the context of where it would be used, or where the facts may be presented as isolated pieces of knowledge, leading the learners to question why they are learning what they are learning. "How does this apply to the real world?" is a common question. James Gee (2008) makes the point, "...that deep learning involves, first and foremost, activity and experience, not facts and information (typical classroom learning)." (pg. 13) Gee also goes on to point out that, "Any actual domain of knowledge, academic or not, is first and foremost a set of activities (special ways of acting and interacting so as to produce and use knowledge) and

experiences (special ways of seeing, valuing, and being in the world).”(pg.1) Virtual environments have been utilized in this regard because they can immerse a learner in a contextual situation where learning is not just an abstract concept. In the aforementioned Chau, et. al. (2011) study, the virtual environment used was set up as a business office, a situation where (computer) system security measures are commonly employed. The participants who were in the virtual environment condition scored over twice as high, on average, as those participants in the non-virtual environment condition.

McQuiggan, Rowe, Lee and Lester (2005) used the Virtual World of *Crystal Island*, a narrative driven learning environment in which learners investigate the source of an infectious disease that is causing the inhabitants of a research station on Crystal Island to fall ill. The learning gains were measured in the study by the scoring difference between a pre-test and a post test. The participants who were in the minimal-narrative and narrative conditions scored 1.3 and 0.5 more questions correctly, on average.

Whitelock, Romano, Jelfs and Brna (2000) investigated learning inside a virtual environment by using software called *The North Atlantic Ridge*. *The North Atlantic Ridge* is a virtual learning environment in which learners use a virtual submarine to explore various locations along the North Atlantic Ridge. The learners can view both the terrain’s geological structures and the biology of the region. A pre and post-test were again used to measure student learning. In the pre-test, the learners in the two experimental conditions, enhanced audio and normal audio, scored 3.3 and 2.9, on a measure of identifying the flora and fauna of the North Atlantic Ridge. On the post test, participants in the normal audio condition scored an average 8 points higher than in the

pre-test and participants in the enhanced audio condition scored an average 4 points higher, indicating learning did occur in both versions of the virtual environment.

### **Visual Fidelity as a Component of Situated Design**

If we are to apply a situated learning design framework into a virtual environment, the look and feel of the VE should be comparable to the real world in order for the experience to seem “authentic.” In doing so, it can be argued that a learner’s sense of presence should increase, along with a corresponding increase in learning.

There may not need to be a true “one-to-one” visual relationship between real world and digital objects in a virtual environment to achieve increased user presence, but the representation should be accurate enough so the experience is not being misrepresented. For example, glass in windows needs to be transparent, but have sharp specular highlights and reflect its surroundings. Curtains should hang as though they are made of some deformable fabric that is being pulled down by gravity and would move and ripple if a virtual wind was blowing through them. Light should bounce around virtual spaces as it does in the real world, so virtual sunlight entering a room with a single window will bounce off, around and through surfaces and would illuminate the room as it does in the real world.

Unfortunately, current computer hardware does not permit truly physically accurate modeling, lighting and rendering, and physics to be computed on the fly together. Since playback speed of a VE has been found to affect a user’s sense of presence in a VE (Barfield & Hendrix, 1995) certain aspects of a VE’s realism have to be sacrificed so the playback speed for the learner can be kept at an acceptable frame rate.

The challenge is to achieve a level of visual fidelity that can promote presence and learning, while maintaining an acceptable level of performance.

Zimmons and Patner (2003) investigated if rendering quality affected presence in a virtual environment. They used three rendering conditions of differing quality and found that all of the conditions produced “similar increases in physiological response implying that presence was experienced in all conditions.” The frame rate had to be lowered across the middle and low conditions to match the slower frame rate of the high quality condition. Mania and Robinson (2004) found similar results when focusing on the shadow accuracy of a render. In their study, shadow accuracy did not affect participants’ sense of presence. In both studies, however, the virtual environments and the objects that populated the spaces were realistic enough looking that the spaces were believable.

### **Visual Realism Research Studies**

Since there are a large number of different elements that go into making a 3D object or scene look real, there is a comparable amount of research on the subject of what elements are the most important in bolstering visual realism. To tie back to situated learning, for the learner’s experience to be authentic, the digital experience should closely approximate the real world experience. In other words, how things look in the digital world should be comparable to how things look in the real world. To support a sense of presence and promote better learning, a higher visual standard should make the virtual environment seem more real and that “realness” should lead to more motivation which will lead to a better and deeper learning of the subject matter presented.



It is ironic that with virtual environments, a medium that is very visually centered, visual fidelity, and in particular higher visual fidelity of the graphics, has generally not been shown to increase the sense of presence of a user. Higher frame rate, lower latency, wider field of view all positively influence reported presence (Khanna, et al., 2006), but there are conflicting results on the subject of visual fidelity increasing presence. Slater, et al. mention that, regarding the mixed findings on visual fidelity and presence, perhaps the higher fidelity graphics have fallen victim to Mashiro Mori's "Uncanny Valley." The "Uncanny Valley" concept states that "improvements in quality might result in improvements in response up to a point after which there might be sudden dip in response due to defect magnification." In other words, high visual fidelity may be associated with high presence up to a certain point of realism. At some point, the visuals are 'too real' ...so close to reality that small defects are easily noticed and bring about a sense of unease in the viewer. Given the fact that there are a number of elements that make up the visual fidelity of a 3D environment (modeling, texturing, lighting and shadows, rendering method, etc.), perhaps not all visual elements are perceived equally by users. The following studies highlight the mixed results from research into visual fidelity, presence and learning.

### **The Case for Higher Fidelity Visuals**

In one of the first studies in this area, Slater, Usoh and Crysonthou (1995), investigated the effects of dynamic shadows on presence and depth perception inside VEs. Study participants were asked to "walk" to a point inside a virtual room and look at an array of spears. They were then asked to choose the one closest to the virtual wall. Results from the study were inconclusive about dynamic shadows effect on depth

perception inside a VE, but dynamic shadows did increase a sense of presence inside a VE for visually dominant subjects. Shadows made the environment seem more real to the users.

Kahana, Yu, Mortensen, and Slater (2006) investigated whether or not a difference in sense of presence could be attributed to the rendering method. The two methods for rendering were ray tracing (RT) and ray casting (RC). The primary difference between the two conditions is that ray tracing allows for the creation of real time shadows and reflections while the ray casting condition does not. So in the RT rendering condition, if an object moves in front of a light, the object will have its shadow cast. If an object is placed in front of a reflective surface, the reflection of the object will be rendered on that surface. The results of the experiment showed that there was a much higher sense of presence reported by participants in the ray tracing treatment than in the ray casting treatment. Once again, accurately rendered, dynamic shadows that move with the user's avatar added to the user's sense of "realness" of the virtual environment.

The same four authors collaborated again on another study in 2009. This study is very similar to their 2006 study, utilizing the same environment, lighting and shadow conditions. The focus of the second study was to investigate the overall visual realism of the rendering, not just dynamic shadows and reflection's effect on user presence. Once again, the ray tracing condition produced a greater sense of user presence. The participants reported feeling as though they were in a place other than the lab where the experiment took place. In addition, the ray tracing group had increased physiological responses (heart rate, mental stress) than the ray casting group, indicating that visual realism was affecting presence.

Lessels and Ruddle (2004) looked at how high fidelity graphics and field of view (FOV), or the angular extent of the observable world that is seen at any given moment, affect performance in a virtual environment. In their study, there were two levels in each of two treatments: high fidelity graphics which used textures from photographs to map the walls of the space, and generic tiled brick pattern used to map the walls in the low fidelity condition. The field of view's "high condition" was 144 degree FOV versus a 48 degree FOV for the low condition. The results of the experiment found that the participants in the high fidelity graphics treatment took less time to complete the navigational search task, which was comprised of searching for eight targets that had been placed in locations around the virtual environment, than participants in the low fidelity condition. They also found out that when high fidelity graphics were coupled with the larger FOV, the participants conducted a search in the virtual environment much like how it would be done in reality. This would be by moving around the perimeter of the search area and scanning for targets within the search area. In this case, higher fidelity graphics aided participants with more efficient completion of tasks.

Mamassian et. al.(1998) investigated the role of cast shadows on perception of surface shape and spatial layout in 3D environments. The study found that "...cast shadows clearly provide very salient cues for the relative dispositions of objects in space, particularly when an object and its cast shadow are moving." In addition to aiding spatial layout, shadows have an impact, though weaker, on the users being able to visualize the shape of the shadow casting object and the object(s) receiving the shadows. This finding could indicate that the absence of shadows in a VE makes the VE seem less visually real and could impact the overall sense of presence a user feels.

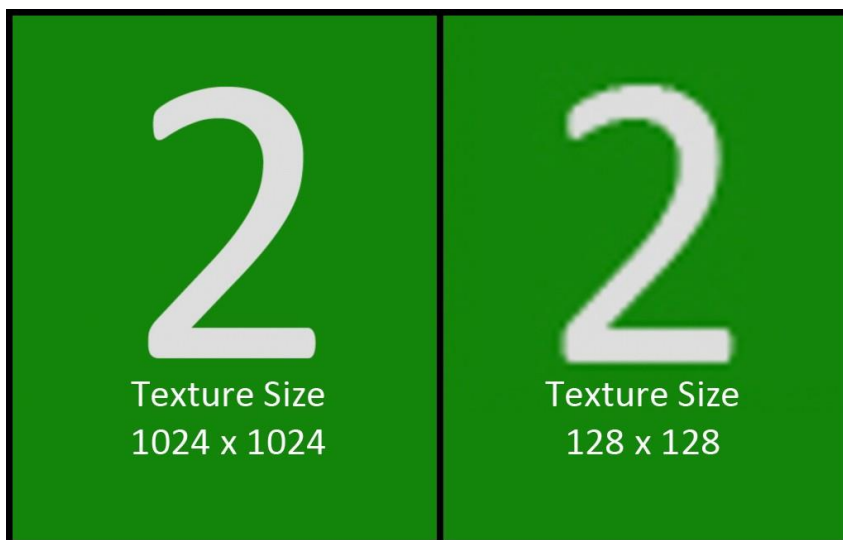
The goal of a research project conducted by Pleban and Beals' (2002) was to determine the effectiveness of training new recruits in the use of night vision goggles inside a virtual environment. There were four conditions tested that offered a combination of graphic fidelity, environmental conditions, and having the soldiers either wear or not wear night vision goggles. The study found that virtual environments, "may offer a safe, effective setting for familiarizing the inexperienced soldier with the fundamental issues involving the use of night vision goggles." In addition, the treatment condition that was rated the most realistic was the one where the rendered image fidelity was the most realistic looking. Omitted visual details were noted by the soldiers that would have made the VE seem even more real, such as muzzle flashes and the lack of modeled streetlights which should have been present. In this case, higher fidelity graphics led to a greater sense of "being there" and was necessary for the soldiers' understanding the limitations of night vision goggles and what to expect visually when wearing them. With this very specific type of training, the training simulation needed to be very accurate so the soldier would have the same experience visually with the goggles inside the VE as they would have in the field. There could not be any misrepresentation or the training would have been less effective.

In each of the previous studies the higher fidelity conditions led to either a greater sense of presence, aided in task completion, or made training seem more authentic and skills transferrable. However, higher fidelity graphics are not always better for every educational or training task and the following studies illustrate that point.

## The Case against Higher Fidelity Visuals

As mentioned previously, for every study with findings that support higher fidelity graphics either enhancing presence or learning inside virtual environments, there is another that contradicts those findings. The following studies illustrate this point.

Zimmons and Panter (2003) investigated how both texture size and lighting condition influenced presence and task performance in a virtual environment. There were two texture sizes, with the larger texture size being 8x larger than the smaller. Smaller texture size leads to blurriness when applied to larger surfaces of a 3D model (Figure 4). The low resolution lighting condition used the scene's default light that produced no shadows while the high resolution lighting condition utilized both non-default scene lights and shadows. They found no significant difference in presence recorded across all experimental conditions. So neither larger texture sizes (which produce sharper rendered surfaces) nor having cast shadows made the environment seem more real.



*Figure 4.* Difference in image clarity due to texture size.

Mania and Robinson (2004) investigated if shadow quality influenced user presence inside a virtual environment. Thirty-six participants were exposed to three versions of a rendered environment: flat shaded (no shadows), and two radiosity rendered scenes set to differing shadow quality levels. The quality levels resulted in the shadows being rendered more accurately. The contents of the virtual room and the light intensity were constant across conditions. The results of the experiment showed no significant difference in presence between conditions, indicating shadow accuracy had no effect on presence. The lack of difference in presence between the two shadow conditions and the no shadow condition seems to contradict Kahana et al. (2006) and Slater et al. (2009) findings about dynamic shadows.

Geudeke (2008) investigated whether a higher texture fidelity leading to a more realistic depiction of a space would allow a participant to gain spatial learning of a virtual environment, in this case a supermarket, quicker than in a lower fidelity condition. In the high fidelity condition, high resolution texture maps were created to surface all of the models leading to a more realistic appearance. The shelves had food on them, the floors were tiled and there were even prices for the various food products. In the low fidelity condition, the textures were omitted and all the models were surfaced with a neutral grey material, the shelves conversely seemed empty and the floor and walls were bare.

The subjects were led on a predefined route through the supermarket and tested on how well they could retrace their steps through the supermarket going from the end of the route back to the start. The findings showed that for spatial knowledge learning the high fidelity condition had a negative impact on the amount of time it took the participants to retrace their route and the number of errors made. In this case, the higher

fidelity condition could have led to a bit of cognitive overload, where the study participant was subjected to so much visual information it actually interfered with their ability to learn the essential information, in this case, the route through the supermarket.

Dinh, H., Walker, N., Song, C. Kobayashi, A. & Hodges (1999) investigated whether additional cues beyond higher fidelity visuals would increase a user's sense of presence in a VE. The researchers added tactile, olfactory and auditory cues to the VE experience while the participants were navigating through the VE. They found that the addition of audio and tactile cues did in fact lead to a greater sense of presence while olfactory cues did not add much. However, the higher fidelity visuals did not add to the participant's overall sense of presence. This fact can possibly be mitigated by noting that the other cues (audio, olfactory, tactile) were either a on or off state for each condition while visuals were always on, being the dominant medium for VR, but at either a high fidelity or low fidelity condition. The differences in the visual low condition consisted of the diffuse texture maps being 1/4 the size of the high visual condition and the use of ambient light only (no shadows) versus ambient and local shadow casting lights.

For the latter grouping of studies, higher fidelity graphics did not aid in learning spatial relationships or create a greater sense of presence for the participants. The next section will introduce the attributes that make up a high fidelity virtual environment, with the emphasis on polygonal modeling, shaders, and lighting.

### **Visual Components of 3D Scenes**

A 3D model is made up of several core elements that when skillfully manipulated can produce a rendered result that when placed side by side with a photo would be

indistinguishable. These core elements would be the polygonal mesh, the shader, and the scene lighting.

## **Polygons**

A polygon is the building block of a 3D model. The polygon itself is a surface that has four or more sides. The sides are made up of polygonal edges and where these edges meet there is a vertex. A polygonal face is the visible surface of the polygon and connects at the vertices of the polygon. These three components: faces, edges and vertices are the primary building blocks, depicted in Figure 5, for the three-dimensional (3D) meshes that make up a virtual environment. The polygonal faces are connected to one another by the edges of the polygons and the vertices at the corners of the polygons. Manipulating individual polygons allows the user to shape the polygons into anything that can be imagined. However, the polygon is a flat surface, so if you looked at the curved surfaces of a mesh edge on, or in silhouette, you will see the flat surfaces clearly. Figure 6 shows the difference in surface roundness between a higher and lower polygon count model. To minimize flatness, a 3D artist would use more polygons to make these surfaces rounder. Typically, the more polygons that are used, the smoother and rounder the curved mesh surface will be. The mesh itself has no surface properties beyond a simple color, usually a midtone greyscale, which the modeling package assigns to it so the 3D model is visible on-screen. What gives a 3D model its realistic appearance is, as described previously, the shader that is applied to a model.



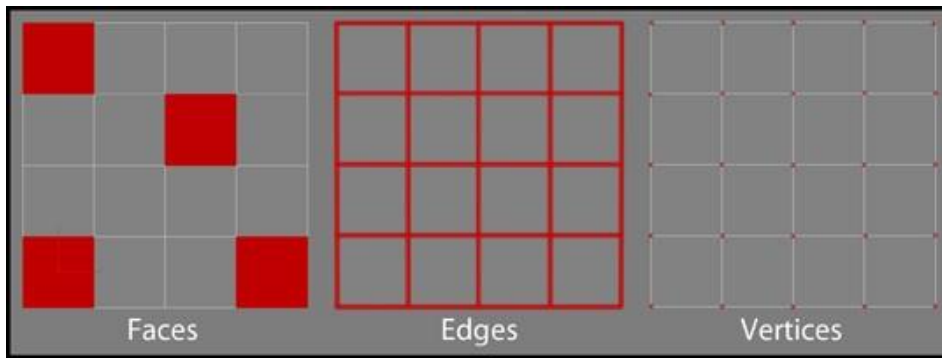


Figure 5. Polygon components

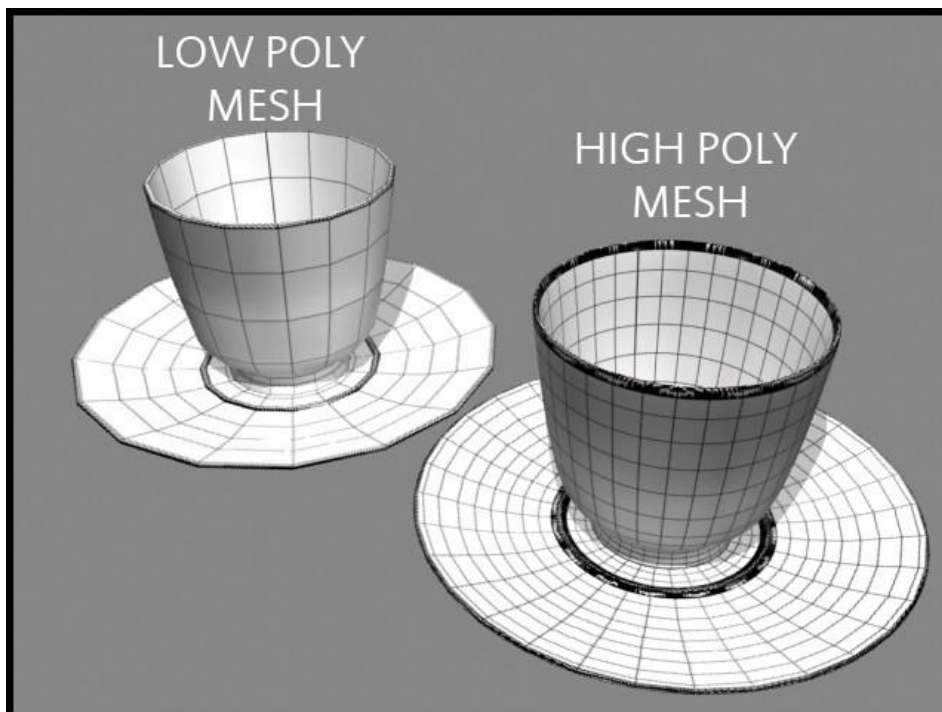


Figure 6. Surface roundness difference between a low and high polygonal mesh.

## Shaders

A shader controls how the 3D polygonal mesh will be rendered. For example, if you were creating glass for a window pane, the glass shader would control: the transparency, the shininess and the color of the polygonal faces of the model. In addition,

it would also control how much the polygons reflect and refract light and other objects inside the scene. Descriptions of common shader parameters can be found in Appendix A.

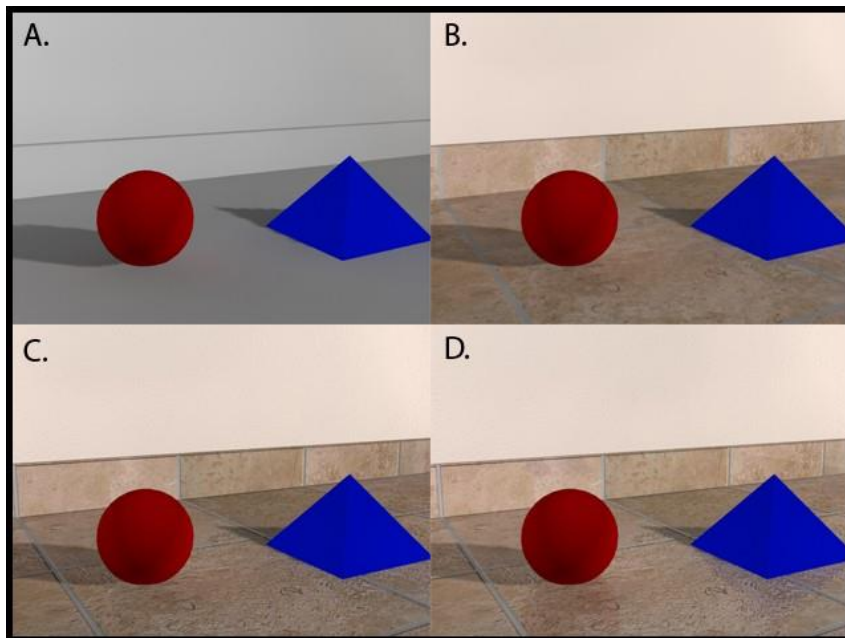
While the attributes on a shader are either solid colors or set to a default value, a content creator can use texture maps or procedural textures to control the various shader attributes. Procedural textures are mathematically generated textures like checkers, gradients, or noise, while texture maps are images that can either be created in a paint program, like *Photoshop*, or captured by using a digital camera. See Figure 7 for examples of procedural textures and texture maps.



*Figure 7.* Examples of procedural textures (top row) and standard texture maps (bottom row).

To illustrate how shaders and textures work together, examine the following four renders of a countertop with a couple of primitive meshes, the sphere and the pyramid, atop it (Figure 8). The first render “A” is with a default grey shader. The surface is grey, because grey is the color that is placed in the shader’s color attribute by default. If you wanted the countertop to render out red, you would replace the grey color with a red color. The countertop surface reacts to light and shadows but does not appear to be

made out of any real world material. In render “B” the grey of the color attribute has been replaced by a brownish tile texture, so the countertop now appears to be made out of tile. However, on closer inspection you might notice that the tile is unusually flat and there does not seem to be any height difference between the tile surface and the depth of the grout lines in between the tiles. In render “C” a bump map has been added to simulate roughness on the tiled surface and create depth to the grout lines. A bump map is a greyscale image, with values running from black to white that simulate height for a shader. When a bump map is added to a shader, black areas of the map render as if that part of the object is recessed while white areas render as if they are protruding outwards. Render “D” is a final version, where reflection has been added to the tiles. This is a quick example of shader development, but you can hopefully see the difference between the shader with only the diffuse attribute mapped, “B” and one with multiple attributes mapped “D.”



*Figure 8:* Render comparison of a shader in development. (A) default grey shader, (B) tile texture replacing color channel, (C) bump map attribute added and (D) reflection attribute added

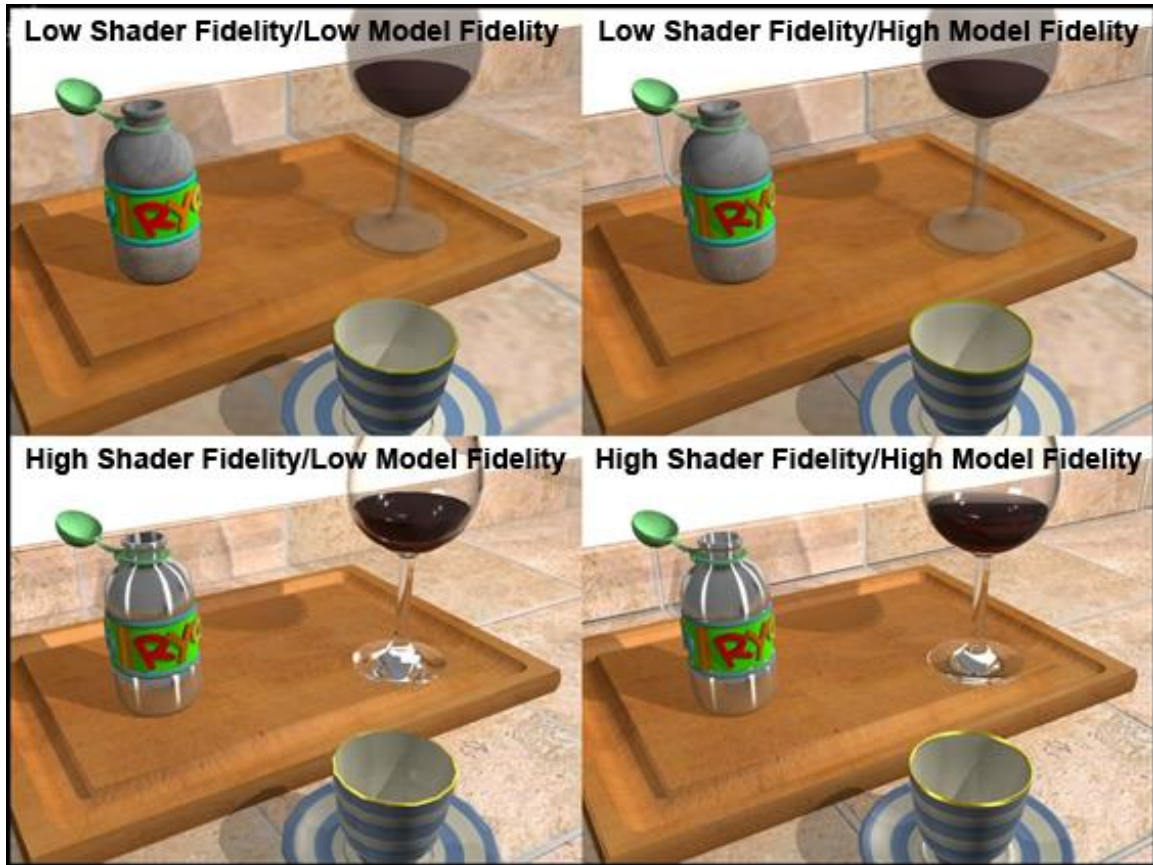
Once a polygonal model has been created, the shader is applied and the scene lit. The process of turning the individual elements into a 2D pre-rendered image (for film or TV) or a 3D real time environment, such as an Xbox game or online virtual environment like a *Second Life* world, is called rendering. A renderer, or rendering engine, takes in all of the data and “draws” or renders the final image.

### **Summary of Research and Hypothesis**

I hypothesize that the mixed findings of learner presence in virtual worlds attributable to visual realism seen in studies to date is related to the environments themselves simply not looking real. This may be due to the fact that the 3D models are constructed poorly, the shader development is lacking and the lighting is not believable.

In the previously discussed studies, only two defined how high and low fidelity visuals differed with regards to the shaders used on the various models. In those two instances, the only difference between a high and low fidelity shader was the size of the texture used to map the diffuse or color attribute of the shader. Mapping or manipulating the diffuse or color attribute on a shader is very important, because it gives a strong visual clue of what a shader is supposed to represent, like concrete, wood or stone. However, manipulating only the diffuse or color attribute is not enough to create a visually believable shader. Multiple attributes need to be manipulated on a shader applied to a model in order for it to be rendered in a semi-realistic to realistic manner.

In this dissertation study, I investigate whether higher fidelity visuals used in an virtual learning environment (VLE) are associated with higher levels of user presence and greater learning than lower fidelity visuals. Renderings of the four visual conditions can be found in Figure 9. The study description, procedures, and measurement instruments will be detailed in the next section.



*Figure 9.* The four rendering conditions: A) Low Fidelity Shader/Low Fidelity Model. B) Low Fidelity Shader/High Fidelity Model (C) High Fidelity Shader/Low Fidelity Model, D) High Fidelity Shader/High Fidelity Model

## Research Questions

There are six research questions in the current study: two dealing with the impact of shader fidelity on learner presence and learning and two dealing with polygonal fidelity's impact on learner presence and learning. The fifth and sixth questions deal with

how shader fidelity and polygon fidelity interaction impacts learner presence and learning. The questions are stated below.

The study is set up and data analyzed as a 2 x 2 between subjects ANOVA. The factors are shader fidelity and model fidelity. There are two levels for each factor, high and low. The combinations of factor level by condition can be found in Table 1.

Table 1

*Factor Level by Condition*

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Condition 1:  Model Fidelity: High Shader Fidelity: High	Condition 2:  Model Fidelity: High Shader Fidelity: Low
Condition 3:  Model Fidelity: Low Shader Fidelity: High	Condition 4:  Model Fidelity: Low Shader Fidelity: Low

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Question 1: To what extent does the use of high fidelity shaders (shaders that have had many attributes manipulated) in a Virtual Learning Environment (VLE) bolster scores on a measure of user presence, compared to a version of the VLE with low fidelity shaders (fewer attributes manipulated)?

Question 2: To what extent does the use of high fidelity 3D models (more detailed/higher polygon count/smooth surfaces) in a VLE bolster scores on a measure of user presence versus the same environment using low fidelity models?

Question 3: To what extent is the use of high fidelity shaders associated with increased learning inside a VLE versus a VLE that uses low fidelity shaders?

Question 4: To what extent is the use of high fidelity 3D models associated with increased learning inside a VLE versus a VLE that uses low fidelity 3D models?

Question 5: Is there an interaction between shader and model fidelity that has an effect, positive or negative, on a learner's sense of presence inside a VLE?

Question 6: Is there an interaction between shader and model fidelity that has an effect, positive or negative, on learning inside a VLE?

## **Variables**

### **Independent Variables**

**Shader Fidelity.** There were two levels to this variable: High and Low.

High Shader Fidelity refers to using texture maps in all necessary shader attributes in order to produce a non-blurry or aliased looking “skin” to the 3D model. The three shader attributes are considered the “most important to know about are diffuse/color maps, normal maps and specular maps (Silverman, 2013). In addition, when talking about texture map creation for shaders, Ahearn (2008), mentions diffuse/color, normal and specular maps as the first maps that are commonly created. In this study, additional maps were used, when necessary, for special effects on the 3D models. Examples of such situations would be if a model was semi-transparent, like a mesh screen (opacity map), or needed to be self-illuminated, like a light bulb (emissive map).

Low shader fidelity refers to using texture maps that are the same size as in the high shader fidelity condition, but the normal and specular maps were removed leaving only the texture in the color attribute. Additional maps were used, when necessary, for

special effects on the 3D models. Descriptions of diffuse/color, specular and normal bump, along with descriptions of additional shader attributes can be found in Appendix A.

**Model Fidelity.** There were two levels of to this variable: High and Low.

High model fidelity refers to a 3D model that represents the real world object accurately in size and form and on close inspection a study participant should not be able to discern the straight edges of the polygons that make up the object's rounded or curved surfaces. In addition, the models had chamfered or beveled edges on their surfaces, to catch highlights in the lit environment.

Low model fidelity refers to a 3D model that represents the real world object well in size and form but on close inspection the low polycount could be seen by observing the rounded or curved surfaces of the model. On these rounded or curved surfaces of the model, straight edges of the polygons that make up the object were noticeable. In addition, all bevels or chamfers were removed.

### **Dependent Variables**

**Presence.** Presence measured the participants immersion or the sense of "being there" inside the virtual learning environment.

**Learner Score.** Measured the participants understanding of the content presented in the virtual environment. This variable had a single level.

### **Supplementary Variables**

There are several demographic variables that were measured using a pre-treatment survey. The information gathered was evaluated to determine whether any surveyed



demographic characteristics affected learning and/or sense of presence in the VE. The variables are as follows.

**Age.** There were four levels to this variable, 18-19, 20-29, 30-39, and 40+

Osberg (1995) reports that as students get older, they enjoy the experience slightly less than younger students. The average game player in the United States is 30 years old (retrieved from [http://www.theesa.com/facts/pdfs/esa\\_ef\\_2012.pdf](http://www.theesa.com/facts/pdfs/esa_ef_2012.pdf)). Most age based gaming demographics are broken down into the under 18, 18-35 and 36 or older ranges. Almost all the students at the Art Institute are within the 18-35 categories so the categories needed to be split. Eighteen was the minimum age to participate in the study so it was used as the base for the first category. The average age of game players of 30 was used to split the middle two age categories. There is also a small population of 40+ students that needed representation.

**Gender.** There were two levels to this variable: male and female.

Gender can also come into play when using VE's for learning. Although gaming is typically thought of as a male dominated endeavor, females make up a large portion of the gaming population. Forty percent of all game players are women. In fact, women over the age of 18 represent a significantly greater portion of the game-playing population (34%) than boys age 17 or younger (18%).  
([http://www.theesa.com/facts/pdfs/esa\\_ef\\_2012.pdf](http://www.theesa.com/facts/pdfs/esa_ef_2012.pdf)).

**Computer Gaming Hours per week.** This measures how much time the participant plays computer games per week. There were five levels to this variable: none, 1-5 hours, 6-10 hours, 11-15 hours, and 15+ hours.

Popular game engines such as the Unreal Development Kit (UDK), Source and Unity have very similar control systems that allow the player to navigate through the 3D environments. Typically the W, S, A and D, keys on a keyboard are used to move forward, backwards, left and right. Interaction with objects in the environment is also similar either using a left mouse button click, as in Blizzard Studios wildly popular game, *World of Warcraft* or by a keystroke, such as the F key in Infinity Ward's *Call of Duty: Modern Warfare 3*. This control system was utilized inside this study's virtual environment. Therefore game players may have an advantage in learning when compared to non-gamers because of the familiarity with the control system. The experienced gamer may be able to better concentrate on the environment while the non-gamer focuses on learning the control system, thus experiencing higher levels of cognitive load. Squire (2005) reported that when introducing gaming into curriculum, 25% of the students complained the game was too hard, complicated, and uninteresting.

**Experience with Virtual Environments.** Like computer gaming experience, previous experience with virtual environments could potentially allow those users to interact inside the VE more easily than participants with no experience. There were four levels to this variable: None, 1-3, 4-6, 7-9 and 10 or more. The demographic survey can be found in Appendix B.

**Time in Virtual Environment.** According to Whitelock (2000), more time on task is indicative of higher presence and more engagement inside a virtual environment. Time spent inside the virtual environment will be tracked for each participant.

## **Measures**

### **Dependent Variables**

**Presence.** Currently there are three main methods for measuring presence in a VE, with each having its strengths and weaknesses. The three methods are: Subjective measures such as a survey, behavioral measures such as observing participants ducking their heads as they go into a tunnel on a virtual ride, and physiological measures such as heart rate.

Although both behavioral and physiological measures have been used successfully in measuring presence in various studies, either measuring instrument is not appropriate for the current study. Insko (2003) points out that in order to get the behaviors and/or physiological responses of the participant you need to “...use a stress-inducing environment so that strong behavioral and physiological responses can be expected.” As mentioned earlier, the setting for the virtual environment in the current study is a chemistry lab and the content of the VE is centered on learning about mercury. The setting and content do not include anything that would alarm the participants. Because of these reasons, the selected instrument was a post VE treatment subjective survey on presence.

There have been several surveys used to measure presence inside a VE but Witmer and Singer’s (1998) survey is easily the most cited. However, popularity alone though will not generate accurate results. The instrument has been validated by running a reliability analysis on “...the combined data from four VE experiments (Lampton et al., 1994, Witmer et al., 1996, Bailey & Witmer, 1994, Singer et al., 1995). The score distributions were similar across experiments and internal consistency measures of reliability (Cronbach’s Alpha) yielded a value of .81 for the presence questionnaire.” The presence questionnaire used in this study can be found in Appendix C.

**Learner Score.** Scores on the dependent variable, learning, were gathered from an investigator generated test given to all participants after exposure to one of the four learning conditions. The subject matter of the exam is on the element mercury and its derivatives. The information used for the test questions was gathered from several sources including the Environmental Protection Agency (<http://www.epa.gov>) and other online sources. The test focuses on both general information such as: atomic number, symbol in the periodic table of elements and more specific information such as what to do in case of mercury exposure.

The assessment instrument consists of twenty (20) questions about the subject matter that can be investigated in the VE. The questions are in multiple-choice format with four (4) possible answers per question to minimize the effect of correctly guessing the answer. Other rules were followed in test question creation as outlined in Burton, Sudweeks, Merrill and Wood (1991). This learning measure can be found in Appendix D.

### **Attitudinal Data**

Attitudinal data about the VLE experience was gathered through the administration of an attitudinal measure post VLE. The attitudinal survey consisted of six Likert scaled questions followed by two open ended questions about the VLE, intended to measure attitudes, positive or negative, towards learning in a VLE, and to see what exhibits and facts about mercury stood out to the participants. The attitudinal survey can be found in Appendix E.

### **Post VLE Interview**

A post VLE interview was conducted with two randomly chosen participants from each condition. The two participants were interviewed separately. The interview

consisted of three open ended questions that allowed the interviewee a wide range of responses about attitudes towards the VLE, and strengths and weaknesses of it. The interview questions can be found in Appendix F.

## CHAPTER 2

### METHODS

#### **Participants**

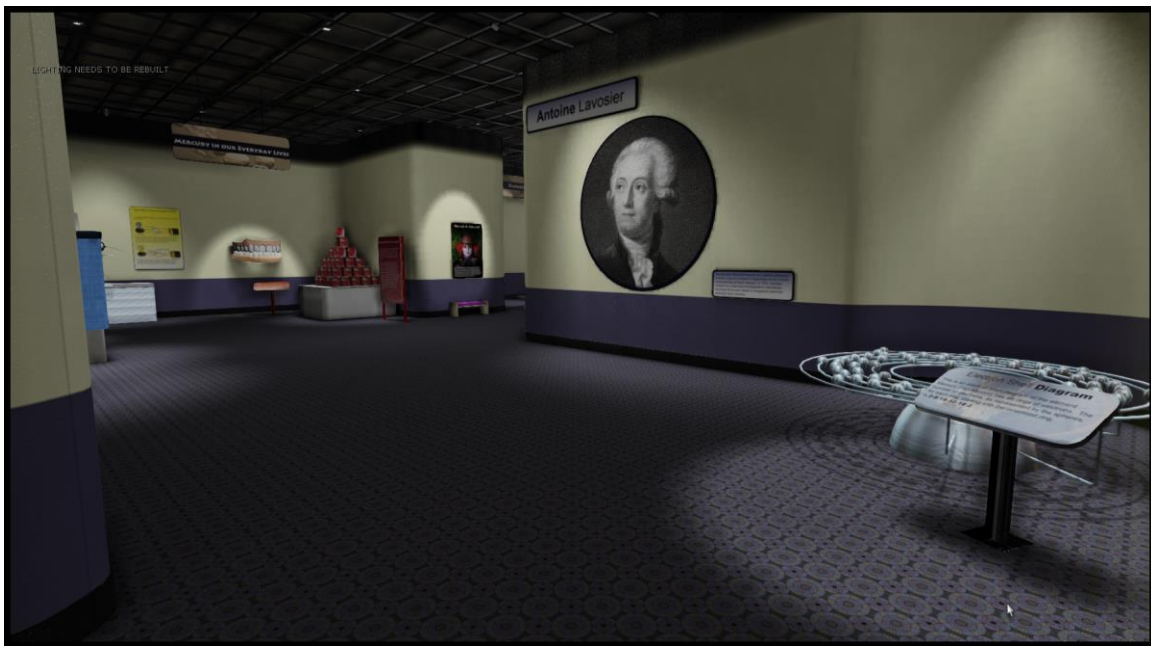
The virtual learning environment used in the study is meant for adult learners and the participants for this study were drawn from the general student population at the Art Institute of Phoenix, a college level institution. The participants were recruited through fliers and classroom announcements. A total of 76 students volunteered to take part in the study. There were forty nine (49) males, twenty five (25) females and two non-disclosed. The gender breakdown of those who volunteered to participate was not quite the same as the overall population breakdown of the school which is 52% male and 48% female. The ages ranged from 18-40+ , with the majority of the participants (54) being in the 20-29 range, followed by the 30-39 range (10). There were six participants in the 18-19 age range and five aged 40+. Subjects were given extra credit by their various instructors for participating in the study. The subjects were randomly assigned to one of the four treatment conditions. Explanation of the study procedure can be found in the *Procedures* section.

#### **Virtual Learning Environment Description**

The VLE is loosely based on contemporary science centers. Large, wide open interior spaces filled with many exhibits of various shapes and sizes that present a participant with information on a variety of subject matter (see figure 10). The participant is free to roam about in this environment inspecting and interacting with the various exhibits and learning stations, each of which will give the participant a bit of information on the element mercury. Being based on a real world environment and scale keeps the

space feeling “real”, but a strength of VLEs is they can provide participants with experiences that would not normally be able to experience. Therefore, this VLE environment also allows for some bending of reality, as in the case of fish swimming through the air or a user controlled mini thunderstorm. It also allows the participant to view and interact with mercury in the exhibits, something that they would normally not be able to do safely in an exhibit.

For a complete breakdown of the contents and activities of the VLE, please refer to the VLE design document in Appendix G.



*Figure 10.* Entryway of the VLE showing some of the exhibits

## **Content**

The content area taught in this Virtual Learning Environment project was an introduction to the element mercury. The subject was chosen for three primary reasons. First, given the fact that mercury can be considered a dangerous material to handle, and that virtual environments are valuable in their support for placing users in training or

learning in situations that would be too dangerous in the real world, the subject matter and medium seem doubly appropriate. Second, the surface of mercury has high specularly and is reflective, so the difference in the low versus high fidelity shader for the mercury will be noticeable when some of the shader attributes are removed. Lastly, the subject of mercury is very broad. It has both historical and scientific information that can be used to make many visually interesting displays or exhibits in which the participant can interact.

### **Curriculum and Learning Objectives**

As mentioned in the previous section, the curriculum of this virtual learning environment (VLE) is focused on the element mercury (Hg). Being a VLE, the curriculum was delivered by having participants move through the VLE, interacting with learning stations and exhibits that populate the space. The participants could explore where they wanted to explore, and to interact with whatever interested them inside the VLE. They could visit the various learning stations and exhibits in any order and glean information about mercury from each of the exhibits that populate the space. There are six (6) distinct areas that the content is broken down into in order to organize the informational material and the VLE itself. Each of these six content areas has its own set of learning objectives (see Appendix H for an expanded list of learning objectives).

The learning areas are as follows:

- 1) Properties of Mercury
- 2) Mercury in our Everyday Lives
- 3) Dangers of Mercury
- 4) How Mercury is Mined



5) Mercury through the Ages

6) Mercury in the Oceans

### Learning Area Descriptions

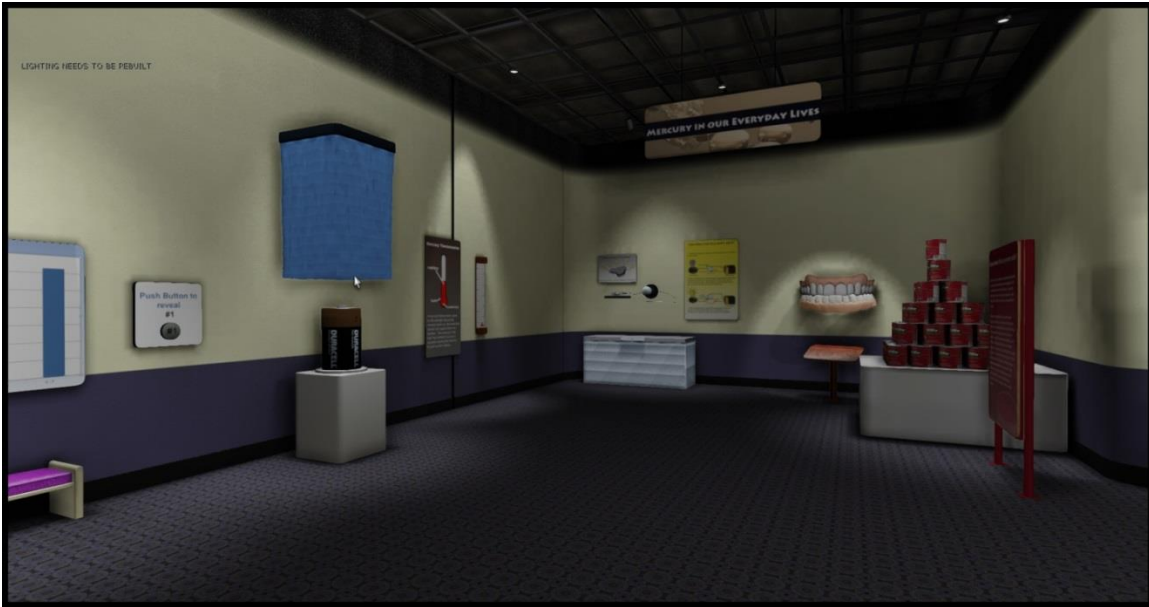
**Properties of Mercury** - In this area, the participant is exposed to information on the chemical properties of the element mercury. Information that can be derived from this area: atomic number, boiling and freezing points, relative density, magnetic properties and number of electrons in the various atomic shells. For a more complete breakdown of all exhibits found inside the VLE, please refer to Appendix G.



*Figure 11. Partial layout of the *Properties of Mercury* area. Exhibits from left to right: *Magnetic station*, *Atomic number*, *Relative Density of Mercury*, *Dunking station*, and *Katy Perry is Hot and cold about Mercury*.*

**Mercury in our Everyday Lives** - In this area, the informational content focuses on mercury containing products that humans are exposed to everyday. The exhibits in this

area are: disposable batteries, mercury in thermometers, mercury switches in appliances, amalgamated dental fillings, and household paint.



*Figure 12. Partial layout of the Mercury In Our Everyday Lives area. Exhibits from left to right: Disposable Battery exhibit, Thermometer, Mercury Switches in Appliances, Amalgamated Dental Fillings and Household Paint.*

**Dangers of Mercury** - This area focuses on the physical problems to a human body that mercury exposure can cause. Information that can be derived from this area: how mercury exposure affects skin, lungs, kidneys and nervous system, different exposure methods, what to do in an event of a mercury spill and dimethylmercury.



Figure 13. Partial layout of the *Dangers of Mercury* area. Exhibits from left to right: Inhale and Cleanup of Mercury exhibit, How Mercury affects the Body, Karen Wetterhahn and Dimethylmercury.

**How Mercury is Mined** - In this area, the informational content focuses on the mining of mercury from the earth. Information that can be derived from this area: which countries mine mercury, mercury is refined from cinnabar ore and how mercury is separated from cinnabar.



*Figure 14.* Partial layout of *How Mercury is Mined* area. Exhibits from left to right: *How Mercury is Extracted from Cinnabar* exhibit and Flags and floor info board on which countries currently mine mercury commercially.

**Mercury through the Ages** - This area focuses on how mercury was used and understood, or misunderstood, in ancient civilizations. Information that can be derived from this area: mercury has been found in the cultures of the Chinese, the Mayans and the Egyptians. Mercury was used in each ancient civilization, rituals for burial or important people and in the case of the Mayans, religious functions. There is also information on how alchemists utilized mercury.



*Figure 15.* Partial layout of the *Mercury Through the Ages* exhibit. From left to right: The *Alchemy* exhibit, and the entrance to the *Egyptian* exhibit.

**Mercury and the Oceans** - This area focuses on how mercury gets into the aquatic food chain and to our dinner tables along with the various dangers from ingesting mercury.

Information that can be derived from this area: the two primary means that mercury gets into the aquatic food chain, how mercury makes its way up the food chain from plankton to large predatory fish and bioaccumulation.

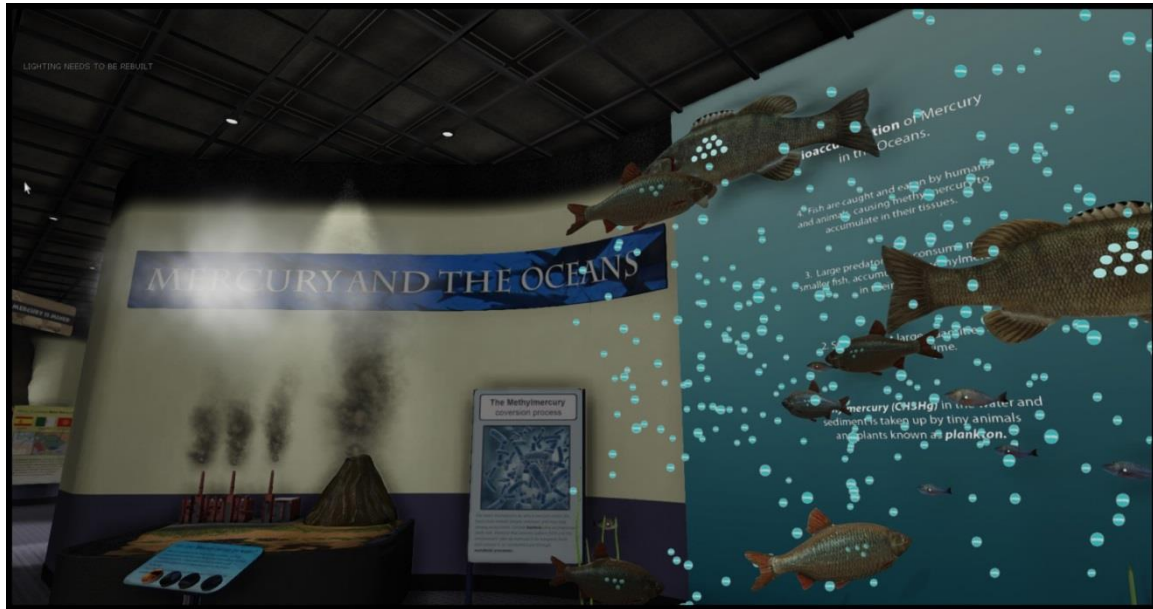


Figure 16. Partial layout of the *Mercury and the Oceans* exhibit. Exhibits from left to right: *How Mercury enters the Oceans* and *Bioaccumulation in Fish*.

### VLE Asset Creation

The 3D models used in the study were created by first modeling out the high fidelity model. The model was unwrapped to provide a UV layout for subsequent texturing and then textured with all maps needed for the high shader fidelity condition: the color, normal and specular maps. Once the high fidelity model was completed, the low fidelity model was created by reducing the polygon count of the high fidelity model until the curved or rounded surfaces of the model were noticeably faceted along with removing the bevels. The low fidelity shader was created by removing both the normal and specular maps from the shader. The texture sizes remained the same for both the high and low fidelity conditions.

## **Game Engine and Hardware**

The VLE was assembled and packaged from the *Unreal Development Kit* version 2013-07. The computers that the VLE was run on were HP Z400 workstations. The CPUs were 3.06 GHz Xeon processors, 6GB of RAM and a Quadro 2000 with 1GB of DDR5 memory. The monitors were HP ZR22w monitors using a resolution of 1920 x 1080. The operating system was *Windows 7 Professional*.

## **Procedures**

### **Pilot Study**

The participants for the pilot study were recruited through publicly posted fliers and classroom announcements. The volunteers were given a brief background on the purpose of the study and handed the measuring instruments. They were given a few moments to fill out the demographic survey.

The subjects were next introduced to the concept of a VE and the equipment used. The participants were then given oral directions before starting the VE and being exposed to a transitional VE. This transitional VE space was modeled as a generic classroom environment at the Art Institute of Phoenix, a space most students can relate to. According to Steinicke et. al (2009), utilizing a transitional virtual environment has a twofold benefit. The transitional environment, "... provides users with an intermediate state between the real world and the target VE" and to "accustom users to the characteristics of VR, e.g., latency, reduced field of view or tracking errors, in a known environment" (p. 21).

The subjects were given directions about movement and object interactions inside the VE via text-based screen prompts while inside the transitional virtual environment.



The tutorial lasted two minutes and seventeen seconds. Upon completion of the tutorial, the door to the main VLE was opened. The participants could continue to move around in the transitional environment or proceed through the door and into the main VLE.

Post VLE, the subjects filled out, using a pencil or pen, the three post-experience instruments: the multiple-choice learning measure, the self-report presence questionnaire, and the attitudinal survey.

There was one additional measuring instrument, the pilot test survey, that was used in the pilot study versus those used in the main study. This survey can be found in Appendix H. The pilot test survey was used to gather information on both the transitional virtual environment (the classroom environment) and the learning virtual environment. The information that was gathered dealt with topics such as technical problems with the virtual environment, visual problems with the virtual exhibits, controller problems and the effectiveness of the transitional virtual environment tutorial on readying the participant in the use of the controls.

### **Main Study**

Participants were recruited in the same way as the pilot study: through publicly posted fliers and classroom announcements. However, word of mouth references for the study from student to student did occur. Upon arrival, the participants were shown to a workstation and handed the packet of measuring instruments including the demographic survey, learning measure, presence questionnaire and attitudinal survey.

Before starting the virtual environment software, all participants in the study were given a moment to fill out the short demographic survey to gather background information about: age, gender, weekly hours of computer gameplay and previous

experience with virtual environments. This instrument allows data to be gathered to assess the extent to which any of the supplementary characteristics affect learning and/or sense of presence in the virtual environment.

The subjects were next introduced to the concept of a VE and the equipment used. The participants were then given oral directions before starting the VE and being exposed to the transitional VE. This transitional VE space and the tutorial on the controls used in the VE was also the same as in the pilot study.

Upon completion of the tutorial, the door to the main VLE was opened. The participants could continue to move around in the transitional environment or proceed through the door and into the main VLE.

Post VLE, the subjects filled out, using pencil or pen, the three post-experience instruments: the multiple-choice learning measure, the self-report presence questionnaire, and the attitudinal survey. After returning all of the above measuring instruments subjects were approached and asked if they had time for a short interview. The first two participants from each condition that had time, and were willing to do a post VLE interview on the overall experience with the VLE, were asked a few open-ended questions on what they thought about the VLE, the most enjoyable aspect of the VLE and the least enjoyable. The questions were written using guidelines provided by McNamara (2009). For each question, the wording was (a) open-ended, the wording was as neutral as possible, (c) the questions were asked one at a time and (d) the questions should be worded clearly.



## **Scoring**

### **Learning Measure**

For the learning measure on knowledge of mercury, multiple choice answers were coded a one (1) for a correct answer and a zero (0) for an incorrect answer. The overall score for each condition was compared using ANOVA to measure the difference in means between participant scores across conditions.

### **Presence Questionnaire**

The presence questionnaire is broken down into four subscales of presence: sensory fidelity, involvement, adaptation/immersion and interface quality. Each question uses a seven point Likert scale, where one (1) is the low and seven (7) is the high score. There were three questions, 13, 16 and 17 that were written in a way that made it necessary to reverse score them in order to add them properly. The subscale score is the sum of each item in the subscale.

### **Reliability of Measuring Instruments: Pilot Implementation**

A pilot test was run on both the VLE and the measuring instruments. The goals of the pilot test were to check for visual and technical problems with the transitional VE and VLE and to check the reliability of the two primary measuring instruments: the learning measure on mercury and the presence questionnaire. There were 11 total participants in the pilot test group.

### **Learning Measure Pilot Results**

The learning measure was a 20 question multiple choice format test on the subject of mercury. The answers for each participant were entered into SPSS, coded with a “1” for correct and a “0” for incorrect. In addition, based off of each participant’s overall

score, they were grouped into one of three categories: high, middle and low. The data was then analyzed by computing the Index of discrimination which addresses how well each group of participants, high, middle and low answered each test item, and looking at the point-biserial correlation which correlates each test item versus overall test performance. A low point-biserial value means that a participant who scored highly overall on the learning measure answered incorrectly on an item while a participant who did not do well on the learning measure answered correctly. Looking at the Corrected Item-Total correlation and using a cutoff of 0.15 for a point-biserial value (Varma, 2006) there are three questions, 2, 7 and 16 that merited further investigation. Questions 2 and 16 were answered correctly by 100% of the participants thus accounting for the 0.000 score. The questions were possibly too easy, but the wording of the question stems was not ambiguous. Both questions 2 and 16 were left in the learning measure due to the fact that both the questions were written following the guidelines for preparing multiple choice tests by Burton, Sudweeks, Merrill and Wood (1991), such as: a) base each item on a specific problem stated clearly in the stem b) use plausible distractors, c) keep the grammar of each alternative consistent with the stem d) word the alternatives clearly and concisely and e) include one and only one correct or clearly best answer in each item. In addition, the information inside the VE that was necessary to answer questions 2 and 16 were in displays that were in close proximity to the entrance of the VE and thus could be one of the first two or three exhibits visited. The effect of primacy on working memory, in which a person better remember the first and last things that were presented (Driscoll, 2004) could also be in play with those two particular questions. Question 7, “Mercury is extracted primarily from this material?” received a -0.66 score on the Corrected Item-

Total. The question was an anomaly since six out of eleven participants did answer the question correctly and of the participants who answered correctly, all were from the middle and upper groups in overall scores. However, the question was changed to “Mercury is extracted primarily from this *element*?” for the experiment. Perhaps the use of the word “material” was too ambiguous and caused confusion, the word “element” is more specific. Overall, Cronbach’s Alpha was acceptable at .777.

### **Presence Questionnaire Pilot Results**

The presence questionnaire was a 22 item instrument based off of Witmer and Singer’s presence questionnaire version 4.0. The 22 items were in a seven point Likert scale format, with each item falling under one of four presence subscales: sensory fidelity, involvement, adaptation/immersion and interface quality. Each category has a role in creating “presence” or “the sense of being there” inside a virtual environment.

As mentioned earlier, the presence questionnaire has previously been validated as reliable by running a reliability analysis on “...the combined data from four VE experiments (Lampton et al., 1994, Witmer et al., 1996, Bailey & Witmer, 1994, Singer et al., 1995). The score distributions were similar across experiments and internal consistency measures of reliability (Cronbach’s Alpha) yielded a value of .81 for the presence questionnaire.” However, a reduced form of the questionnaire was used in the pilot study to reduce the amount of post VE paperwork that needed to be completed by participants. Consequently, a reliability analysis was run on the reduced Presence Questionnaire as a whole and on each individual category of question. As a whole, Cronbach’s Alpha was .879, indicating good internal consistency for the scale. Only one item on the scale, question 17, scored negatively in the Corrected Item-Total Correlation

and would raise Cronbach's Alpha the most if the item was deleted. This question was worded "How much did the control devices interfere with the performance of assigned tasks or with other activities?". The reliability result is not unexpected based on the verbal and written feedback received during post experiment feedback. There were many mentions of awkwardness when trying to click on objects inside the VE due to the non-centered cursor. The question was left in the presence questionnaire.

### **Presence Subscales Pilot Results**

The presence questionnaire was broken down into four subscales. A reliability analysis was run on each category of question in the pilot implementation and the results are as follows broken down by category:

#### **Sensory Fidelity**

The sensory fidelity subscale consisted of three questions. After running the reliability analysis in the pilot study, the scale overall had a low level of internal consistency measured by the Cronbach's Alpha of 0.579. Looking at the data, Q4 "How much did the auditory aspects of the environment involve you?" had the widest range of user responses. The responses ran the entire scale from 1-low, to 7-highest, with three respondents choosing 1. Further investigation found that two of the three respondents who chose a 1 for the question wrote on the presence questionnaire that they had the sound turned off on their computer, and the third respondent did not indicate whether the sound was off or not. Furthermore, during the pilot test, not all the planned sounds had been added to the VE. Additional sounds were added to the final VEs.

### **Involvement**

The involvement subscale consisted of ten questions. The scale overall had a high level of internal consistency. Cronbach's Alpha was 0.873 for the category. Two items, Q8, "How compelling was your sense of moving around inside the virtual environment?" and Q20 "How easy was it to identify objects through physical interaction inside the virtual environment; like touching and object, walking over as surface, or bumping into a wall or object?" would have raised Cronbach's Alpha slightly if deleted.

### **Adaptation/Immersion**

The adaptation/immersion subscale consisted of seven questions. The scale overall had a high level of internal consistency. Cronbach's Alpha was 0.737 for the category. Two Items, Q19, "How completely were your senses engaged in this experience?" and Q22, "How easily did you adjust to the control devices used to interact with the virtual environment?" would lead to a slightly higher Cronbach's Alpha if deleted.

### **Interface Quality**

The interface quality subscale consisted of three questions. The scale overall had a moderately high level of internal consistency measured by the Cronbach's Alpha of 0.659. Only Q17, "How much did the control devices interfere with the performance of assigned tasks or with other activities?" would have increased Cronbach's Alpha if deleted. As mentioned earlier, there were some issues with the mouse cursor interface so that result is not unexpected.

## CHAPTER 3

### RESULTS

#### Learning

Scores across all conditions were fairly similar, with the highest mean score on the learning measure coming from the combination of the low shader fidelity/low model fidelity, followed by high shader fidelity/high model fidelity and high shader fidelity/low model fidelity. The low shader fidelity/high model fidelity had the lowest scores by combination of shader condition and model condition (see Table 2 and Figure 17).

Table 2

*Means and Standard Deviations for Learner Score by Shader and Model Fidelity*

Shader Fidelity	Model Fidelity	<i>M (percentage correct)</i>	<i>SD</i>	<i>N</i>
Low	Low	75.0%	9.45%	19
High	High	70.8%	18.2%	19
High	Low	70.8%	16.0%	19
Low	High	67.7%	18.8%	19

The data was normally distributed as ascertained by analyzing the studentized residuals. No residuals were more than  $\pm 3$  standard deviations from the norm. There was also homogeneity of variances, as assessed by Levene's Test of Homogeneity of Variance ( $p = .075$ ).

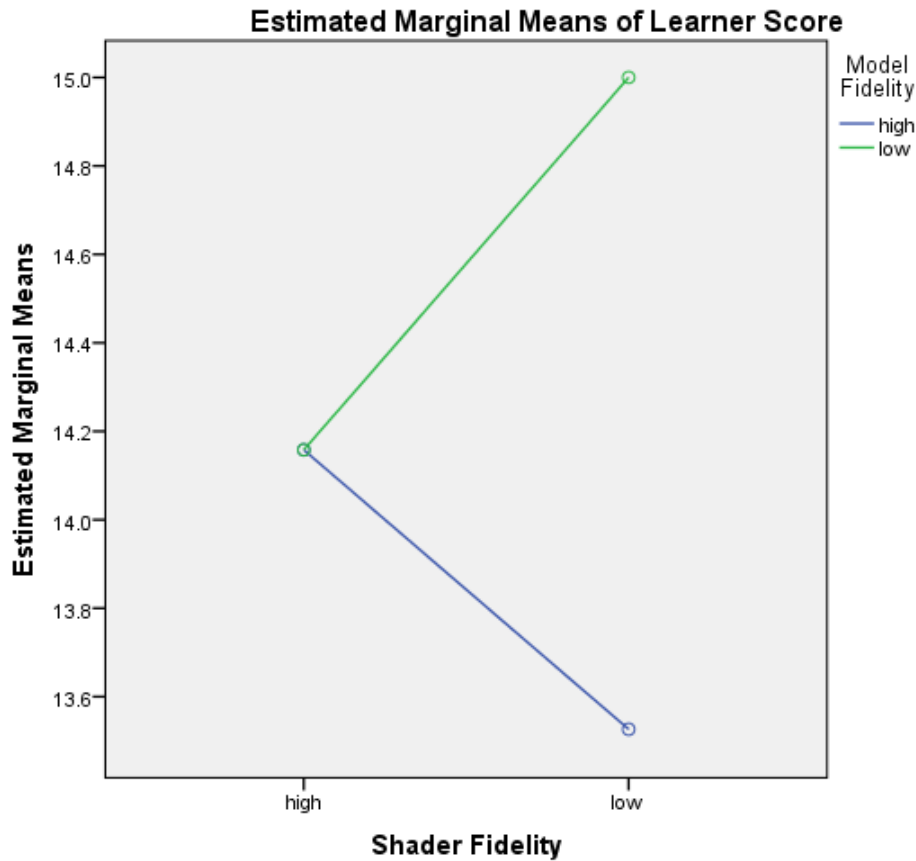


Figure 17. Estimated marginal means of shader and model fidelity on learner score

There were no statistically significant findings for the main effects of shader fidelity  $F(1,72) = .020, p = .982, \text{partial } \eta^2 = .000$  or model fidelity  $F(1,72) = 1.001, p = .320, \text{partial } \eta^2 = .014$  on learner score. In addition, there was no statistically significant interaction between shader fidelity and model fidelity on learner score  $F(1,72) = 1.001, p = .320, \text{partial } \eta^2 = .014$ .

### Presence Subscales

Two way ANOVAs were run on both independent variables, shader fidelity and model fidelity, to investigate whether or not the variables had a significant effect on any of the presence subscales: sensory fidelity, involvement, adaptation/immersion and interface quality. The results are presented in the following sections.

## Sensory Fidelity

The data for sensory fidelity was found to be normally distributed by analyzing the studentized residuals. No residuals were more than  $\pm 3$  standard deviations from the norm. There was homogeneity of variances as assessed by Levene's Test of Homogeneity of Variance ( $p = .510$ ).

The two high model fidelity conditions had the highest mean scores overall on the sensory fidelity presence subscale with values of 17.84 and 16.84 respectively. Mean scores across the four conditions were similar with only a difference of 1.32 from the highest mean, the high shader fidelity/high model fidelity condition, to the lowest score by the low shader fidelity/low model fidelity condition. The data is laid out below in both Table 3 and Figure 18.

Table 3

*Means and Standard Deviations for Sensory Fidelity by Shader and Model Fidelity*

Shader Fidelity	Model Fidelity	<i>M</i>	<i>SD</i>	<i>N</i>
High	High	17.84	2.54	19
Low	High	16.84	3.00	19
High	Low	16.74	2.73	19
Low	Low	16.42	2.46	19



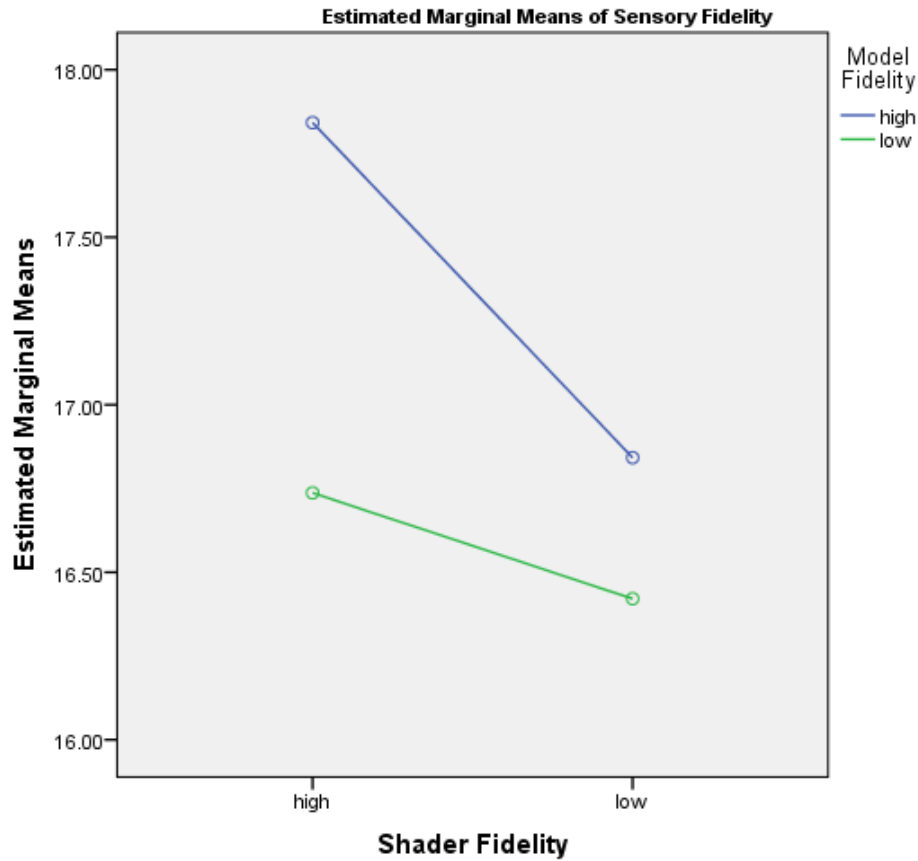


Figure 18. Estimated marginal means of shader and model fidelity on sensory fidelity

There were no statistically significant findings for the main effects of shader fidelity,  $F(1,72) = 1.136$ ,  $p = .290$ , partial  $\eta^2 = .016$  or model fidelity,  $F(1,72) = 1.528$ ,  $p = .220$ ,  $\eta^2 = .02$  on sensory fidelity. There was also no statistically significant interaction between shader fidelity and model fidelity on sensory fidelity  $F(1,72) = .307$ ,  $p = .581$ , partial  $\eta^2 = .016$ ).

## Involvement

The data for involvement was normally distributed by analyzing the studentized residuals. No residuals were more than  $\pm 3$  standard deviations from the norm. There

was homogeneity of variances in the data as assessed by Levene's Test of Homogeneity of Variance ( $p = .156$ ).

The two high shader fidelity conditions had the highest mean scores overall on the Involvement presence subscale with values of 53.58 and 52.68 respectively. The low shader fidelity/low model fidelity condition once again had the low mean score of the group at 50.74 and the low shader fidelity/high model fidelity condition had the third highest mean score at 51.63. The data is laid out below in both Table 4 and Figure 19.

Table 4

*Means and Standard Deviations for Involvement by Shader and Model Fidelity*

Shader Fidelity	Model Fidelity	<i>M</i>	<i>SD</i>	<i>N</i>
High	Low	53.58	4.15	19
High	High	52.68	6.05	19
Low	High	51.63	5.76	19
Low	Low	50.74	5.30	19

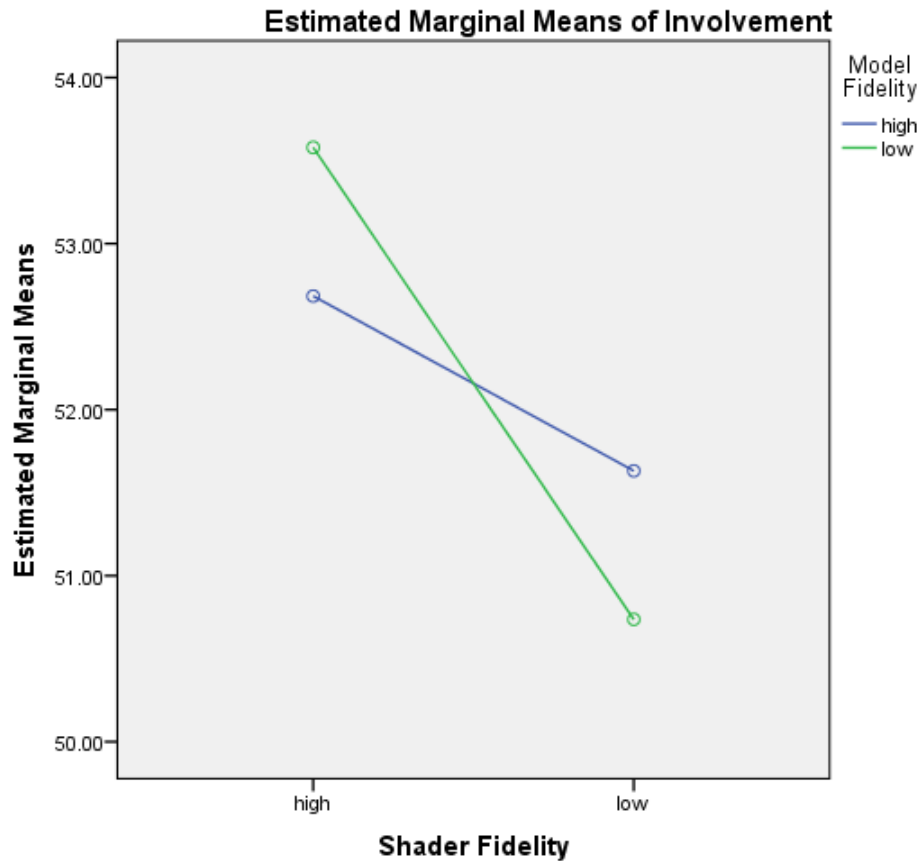


Figure 19. Estimated marginal means of shader and model fidelity on involvement.

There were no statistically significant findings for the main effects of shader fidelity,  $F(1,72) = 2.505$ ,  $p = .118$ , partial  $\eta^2 = .034$  or model fidelity  $F(1,72) = 0.00$ ,  $p = 1.000$ , partial  $\eta^2 = .000$  on involvement. There was also no statistically significant interaction between shader fidelity and model fidelity on involvement  $F(1,72) = .0529$ ,  $p = .469$ , partial  $\eta^2 = .007$ ).

### Adaptation/Immersion

The data for adaptation/immersion was normally distributed by analyzing the studentized residuals. No residuals were more than  $\pm 3$  standard deviations from the

norm. There was homogeneity of variances in the data as assessed by Levene's Test of Homogeneity of Variance ( $p = .413$ ).

Unlike the previous two subscales in which it had the lowest mean score, the low shader fidelity/low model fidelity condition had the highest mean score on this particular subscale, followed very closely by the high shader fidelity/high model fidelity condition. The difference in means scores between the two conditions was only one tenth of a point, 41.84 versus 41.74 respectively. The high shader fidelity/low model fidelity condition scored 40.63 with the low shader fidelity/high model fidelity condition had the lowest mean score with 38.97. The data is laid out below in both Table 5 and Figure 20.

Table 5

*Means and Standard Deviations for Adaptation/Immersion by Shader and Model Fidelity*

Shader Fidelity	Model Fidelity	<i>M</i>	<i>SD</i>	<i>N</i>
Low	Low	41.84	3.75	19
High	High	41.74	5.00	19
High	Low	40.63	4.57	19
Low	High	38.97	6.51	19

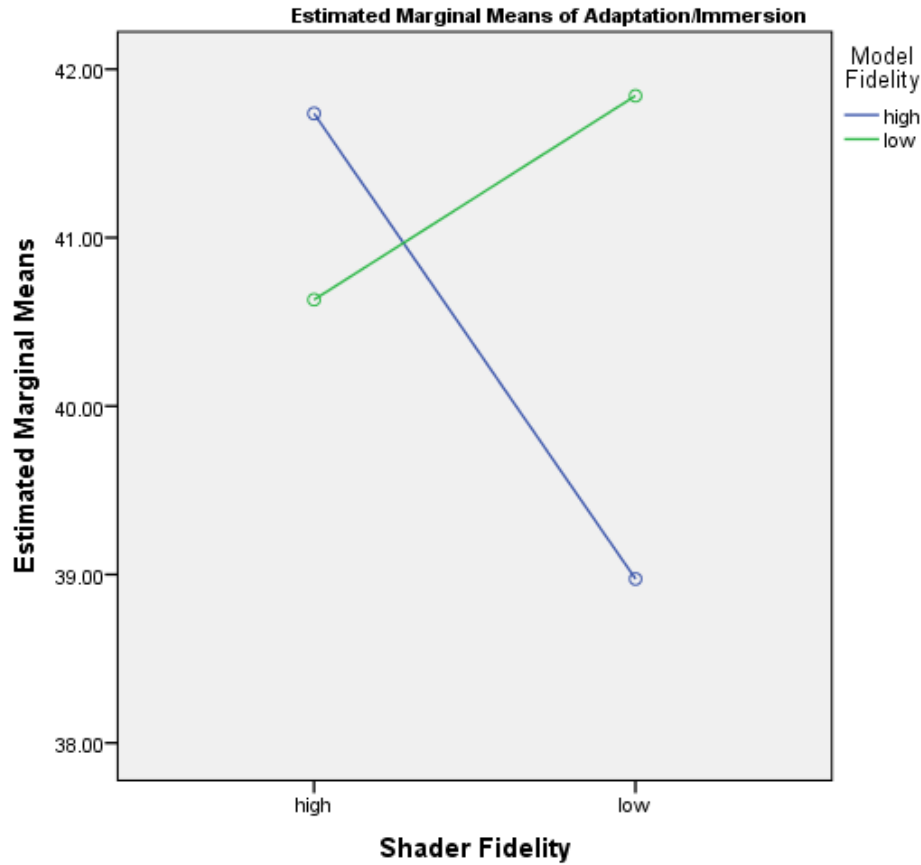


Figure 20. Estimated marginal means of shader and model fidelity on adaptation/immersion.

There were no statistically significant findings for the main effects of shader fidelity,  $F(1,72) = .448$ ,  $p = .505$ , partial  $\eta^2 = .006$  or model fidelity  $F(1,72) = .578$ ,  $p = .450$ , partial  $\eta^2 = .008$  on adaptation/immersion. There was also no statistically significant interaction between shader fidelity and model fidelity on adaptation/immersion  $F(1,72) = 2.934$ ,  $p = .091$ , partial  $\eta^2 = .039$ .

### Interface Quality

The data for interface quality was normally distributed by analyzing the studentized residuals. No residuals were more than  $\pm 3$  standard deviations from the

norm. There, however, was not homogeneity of variances as assessed by Levene's Test of Homogeneity of Variance ( $p = .035$ ).

Mean scores across the four conditions were similar with only a difference of 1.69 from the highest mean, the high shader fidelity/low model fidelity condition, with a mean score of 16.53, to the lowest score by the low shader fidelity/high model fidelity condition with a score of 14.84. The low shader fidelity/low model fidelity condition had the second highest mean score with 16.16 and the high shader fidelity/high model fidelity condition had a mean score of 16.00. The data is laid out below in both Table 6 and Figure 21.

Table 6

*Means and Standard Deviations for Interface Quality by Shader and Model Fidelity*

Shader Fidelity	Model Fidelity	<i>M</i>	<i>SD</i>	<i>N</i>
High	Low	16.53	2.89	19
Low	Low	16.16	3.37	19
High	High	16.00	4.00	19
Low	High	14.84	4.19	19

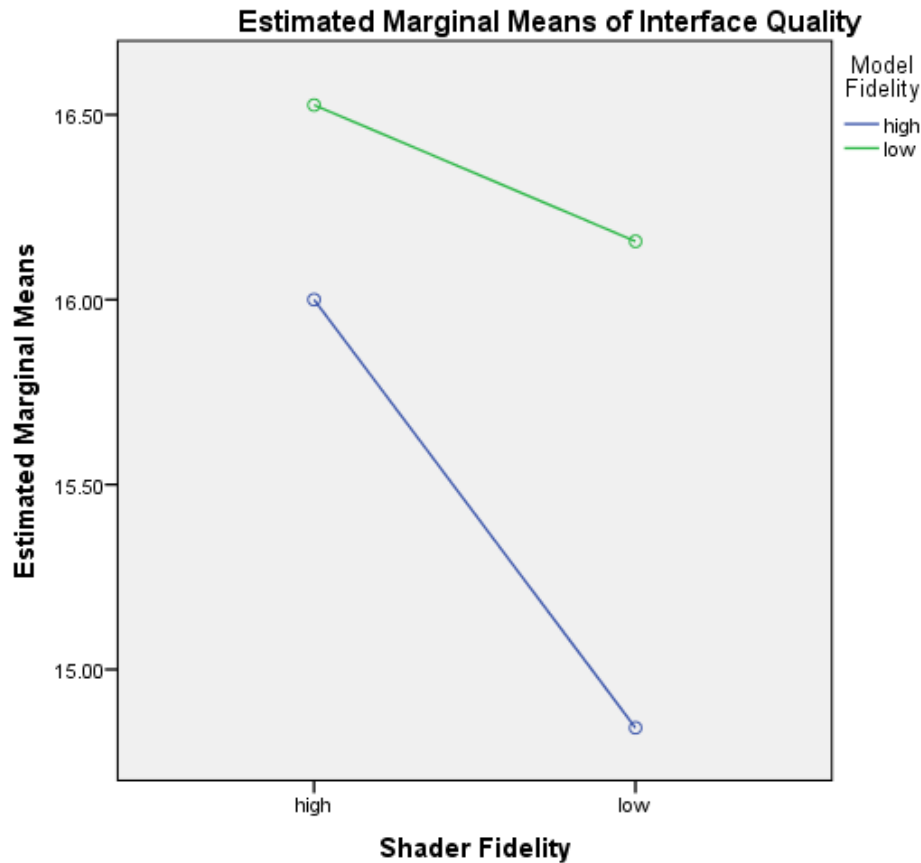


Figure 21. Estimated marginal means of shader and model fidelity on interface quality.

There were no statistically significant findings for the main effects of shader fidelity,  $F(1,72) = .832, p = .365$ , partial  $\eta^2 = .003$  or model fidelity  $F(1,72) = .578, p = .450$ , partial  $\eta^2 = .008$  on interface quality. There was also no statistically significant interaction between shader fidelity and model fidelity on interface quality  $F(1,72) = 1.212, p = .275$ , partial  $\eta^2 = .017$ .

### Supplemental Analysis

Five secondary variables were also gathered based on those used in Slater, Khanna, Mortensen and Yu (2009) and Whitelock (2000) to examine their relationship to the two dependent variables. The five secondary variables were: age, gender, computer

gaming experience, number of virtual environments experienced and time in virtual environment. One-way ANOVAs were run with each supplemental variable, except time in virtual environment, which only had a single level to the variable so Spearman's rank order correlation was used, on both learner score and each presence subscale. There were two significant findings with the secondary variables. First, the participant's gender played a role in how much presence was reported. Second, the amount of computer gaming hours per week had a positive effect on learner score.

### **Gender and Presence**

Female participants reported higher mean presence scores in all four presence subscales: sensory fidelity, involvement, adaptation/immersion and interface quality than their male counterparts. The results for each subscale follow.

#### **Sensory Fidelity**

There was a single outlier in the data, as assessed by inspection of a boxplot. The female group scores were not normally distributed, as assessed by Shapiro-Wilk's test ( $p < .05$ ). There was homogeneity of variances for sensory fidelity scores for males and females, as assessed by Levene's test for equality of variances ( $p = .901$ ). Female sensory fidelity mean scores ( $M = 18.20, SD = 2.40$ ) were higher than those of the male group ( $M = 16.22, SD = 2.59$ ). There was a statistically significant difference in mean sensory fidelity scores between males and females  $F(1, 72) = 10.1, MSE = 2.53, p = .002, \eta^2 = .123$ .

#### **Involvement**

There were no outliers in the data, as assessed by inspection of the boxplot. The involvement subscale scores were normally distributed for each level of gender, as



assessed by Shapiro-Wilk's test ( $p > .05$ ), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ( $p = .166$ ). Female involvement scores ( $M = 54.68$ ,  $SD = 4.05$ ) were higher than that of the male group ( $M = 50.67$ ,  $SD = 5.46$ ). There was a statistically significant difference in mean involvement scores between males and females  $F(1,72) = 10.48$ ,  $MSE = 5.04$ ,  $p = .002$ ,  $\eta^2 = .127$ .

### **Adaptation/Immersion**

There were two outliers in the data, one in male and one in female group, as assessed by inspection of the boxplot. Adaptation/immersion subscale scores were not normally distributed for the female group ( $p < .05$ ) but were for the male group ( $p = .530$ ), as assessed by Shapiro-Wilk's test. There was homogeneity of variances, as assessed by Levene's test ( $p = .917$ ). The scores for the female group were higher in the adaptation/immersion presence subscale ( $M = 42.36$ ,  $SD = 5.14$ ) than the male group ( $M = 39.83$ ,  $SD = 4.86$ ). There was a statistically significant difference in mean adaptation/immersion scores between males and females  $F(1,72) = 4.328$ ,  $MSE = 4.95$ ,  $p = .041$ ,  $\eta^2 = .057$ .

### **Interface Quality**

There was a single outlier in the data, as assessed by inspection of a boxplot. As with the sensory fidelity and adaptation/immersion subscales, scores were not normally distributed for the female group ( $p < .05$ ) but were for the male group ( $p = .148$ ), as assessed by Shapiro-Wilk's test. There was homogeneity of variances, as assessed by Levene's test for equality of variances ( $p = .317$ ). Female interface quality scores ( $M = 17.60$ ,  $SD = 3.06$ ) were higher than that of the male group ( $M = 15.12$ ,  $SD = 3.61$ ). There

was a statistically significant difference in mean involvement scores between males and females  $F(1,72) = 8.59$ ,  $MSE = 3.44$ ,  $p = .005$ ,  $\eta^2 = .107$ .

### Computer Gaming Experience

Computer game playing experiences (measured as the number of hours the participant playing computer games per week) had a significant main effect on learner score  $F(4,70) = 4.613$ ,  $p = .002$ . Participants that reported playing 15 or more hours of computer games per week scored highest ( $M = 90.0\%$ ,  $SD = 9.5\%$ ) while the participants in the 1-5 hour range showed the lowest mean learner scores ( $M = 64.2\%$ ,  $SD = 14.7\%$ ). See Table 7 for all groups.

Bonferroni post hoc analysis revealed that the mean increase from 15+ hours ( $M = 18.0$   $SD = 1.90$ ) from 1-5 hours of gameplay per week ( $M = 12.83$   $SD = 2.93$ ), was statistically significant a mean increase of 5.167, 95% CI [1.36, 8.97].

Table 7

*Means and Standard Deviations for Learner Score by Hours Playing Computer Games per Week*

Hours Playing Computer games Per Week	<i>M</i>	<i>SD</i>	<i>N</i>
None	71.2%	13.9%	17
1-5	64.2%	14.7%	30
6-10	75.6%	16.6%	20
11-15	70.0%	7.05%	2
15+	90.0%	9.5%	6

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### Time in Virtual Environment

Three out of the four conditions had very similar means for time inside virtual environments with roughly 30 minutes. . However, the mean time inside virtual environment for the high shader fidelity/low model fidelity was almost eight minutes more at 37.74. Post-hoc analysis showed that participants did spend longer amounts of time, on average, inside the two high shader fidelity conditions. The results were only marginally significant though,  $F(1,72) = 2.677, p = .053$ , with participants spending more time inside both of the high shader fidelity conditions. The means and standard deviations for time by condition can be found in Table 8. The range of time was quite disparate, with the longest amount of time inside the virtual environment being 60 minutes and the shortest being 12.

Table 8

*Means and Standard Deviations for Time in Virtual Environment by Condition*

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Shader Fidelity	Model Fidelity	<i>M (Time in Minutes)</i>	<i>SD</i>	<i>N</i>
High	Low	37.74	12.82	19
High	High	30.21	11.00	19
Low	High	29.53	9.82	19
Low	Low	29.16	9.48	19

---

## Attitudinal Results

An attitudinal survey was also administered post VLE to measure participant attitudes towards the VLE experience, and to see what exhibits and facts about mercury stood out to the participants. The attitudinal survey consisted of six Likert scaled questions followed by two open ended questions about the VLE.

Overall, there were generally positive attitudes towards the VLE experience across both genders. Females rated the experience slightly more positive than the males but the difference was not statistically significant,  $F(1,74) = 3.361$ ,  $p = .071$ . On a 7 point Likert scale the range of values for both genders was 3-7. Item 4, “I was motivated to try all of the various learning stations” had the highest mean score with both genders, with mean scores of 6.58 for the males and 6.88 with the females. A table with a breakdown of means and standard deviations for each attitudinal item by gender can be found in Table 9.

Table 9

*Means and Standard Deviations for Attitudes Towards the VLE by Gender*

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1. I feel the VLE made me concentrate more while learning.

Gender	M	SD	Min	Max
Male	5.54	1.07	3	7
Female	5.69	1.23	3	7

2. I think the use of VLEs can strengthen my intentions to learn about mercury versus traditional classroom presentation and experimentation.

Gender	M	SD	Min	Max
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Male	5.98	1.18	3	7
Female	6.42	.86	4	7
3. The VLE was an engaging way to learn about mercury.				
Gender	M	SD	Min	Max
Male	6.35	.70	5	7
Female	6.54	.76	4	7
4. I was motivated to try all of the various learning stations.				
Gender	M	SD	Min	Max
Male	6.58	.58	5	7
Female	6.88	.33	6	7
5. I would use a VLE to learn about additional subjects in the future.				
Gender	M	SD	Min	Max
Male	6.19	1.14	3	7
Female	6.69	.62	5	7
6. Overall, I think the VLEs are good learning tools.				
Gender	M	SD	Min	Max
Male	6.42	1.05	3	7
Female	6.65	.69	4	7

---

Younger participants rated the experience more favorably than older participants based on the descriptive statistics, but the differences were not significant  $F(3,71) = 1589, p = .200$ . Results can be found in Table 10.

Table 10.

*Means and Standard Deviations for Attitudes Towards the VLE by Age*

1. I feel the VLE made me concentrate more while learning.

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Age	M	SD	Min	Max
18-19	6.17	.98	5	7
20-29	5.63	1.09	3	7
30-39	5.20	1.40	3	7
40+	5.60	1.14	3	7

2. I think the use of VLEs can strengthen my intentions to learn about mercury versus traditional classroom presentation and experimentation.

Age	M	SD	Min	Max
18-19	6.83	.41	6	7
20-29	6.24	.95	3	7
30-39	5.60	1.51	3	7
40+	5.40	1.52	3	7

3. The VLE was an engaging way to learn about mercury.

Age	M	SD	Min	Max
18-19	6.83	.41	6	7
20-29	6.44	.72	4	7
30-39	6.30	.82	5	7
40+	6.00	.71	5	7

4. I was motivated to try all of the various learning stations.

Age	M	SD	Min	Max
18-19	6.83	.41	6	7
20-29	6.70	.54	5	7
30-39	6.60	.52	6	7
40+	6.60	.55	6	7

5. I would use a VLE to learn about additional subjects in the future.

Age	M	SD	Min	Max
18-19	6.67	.82	5	7
20-29	6.39	1.02	3	7
30-39	6.20	1.14	4	7
40+	6.20	1.10	5	7

6. Overall, I think the VLEs are good learning tools.

Age	M	SD	Min	Max
18-19	6.83	.41	6	7
20-29	6.56	.90	3	7
30-39	6.10	1.29	4	7
40+	6.40	.89	5	7

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## Interviews

Interviews were conducted with two randomly chosen participants from each condition. The information gathered in the interviews mirrored the generally positive attitudes of the survey responses. In addition, two primary themes emerged. First, the

participants liked the interactive aspect of the virtual environment. Secondly, the control system, specifically the mouse cursor, with it not being fixed to a point on the screen, made it difficult to click on interactive elements. Two of the participants mentioned the mouse cursor being a problem.

“Great way to get visual learners to learn. Liked the auditory aspect of too.” said a 20-29 year old female participant in the high shader fidelity/high model fidelity condition. A 20-29 year old male participant in the same condition mentioned that “It (the VLE) was more entertaining than reading about it.” This statement was echoed by two other participants in from different conditions, a 20-29 year old female participant in the low shader fidelity /high model fidelity condition and a 20-29 non-gender specific participant in the high shader fidelity/low model fidelity condition. The interactivity of the VLE was mentioned by two of the interviewees as being a positive in the experience. “Being a kinesthetic learner, having to go up to an exhibit and interact was a plus,” said a 20-29 year old female participant in the high shader fidelity/low fidelity polygon condition.

Not all of the comments were positive though. There were both technical and visual problems mentioned with the VLE. The most commonly reported technical problem was with the mouse cursor, the primary means of clicking on objects in the VLE. The mouse interface was not fixed in the center of the viewport like a crosshair of a gun in a typical FPS, so as the participants moved and looked around in the VLE, the cursor became off centered. Thus, when the participants needed to click on a button or interactive object inside the VLE, it was an awkward experience. Two participants in the interviews mentioned this issue, one from the low shader fidelity/low model fidelity



condition and one from the high shader fidelity /high model fidelity condition. This same complaint was overheard informally a number of times from participants post experiment.

For visual problems, one participant reported some lag in the high shader fidelity/low model fidelity condition around the fluid simulation of the *Dunking Station*. There were a couple of instances of text on the exhibits being hard to read. “The text color was a little light on the (*How Mercury affects the Body*) exhibit,” mentioned a 20-29 year old male from the high shader fidelity/low model fidelity condition and a 20-29 male from the *high* shader fidelity/high model fidelity condition. There was also a mention of the “particle bubbles interfering with reading the background text,” in the *Bioaccumulation* display.

With regards to the exhibits, the participants tended to remember the more visually stimulating exhibits like the *Bioaccumulation* (swimming fish), *How Mercury Affects the Body* (see-through human model with highlighted organs), and the *Dunking Station* (dropping cannonballs into vats of mercury and water). These anecdotal findings are not really surprising. The three aforementioned exhibits all had movement built into the setup. That movement is going to draw the participants closer to see what the exhibit is about in comparison to a very static exhibit like *Mercury in Paint*, which has no moving parts to the exhibit. The *Bioaccumulation* station had the most animated elements of any of the exhibits, and during post VLE interviews, two participants mentioned that there were so many fish in the exhibit that it became hard to read the explanatory text about how mercury bioaccumulates in the food chain. The *Dunking Station* was the only exhibit that utilized a fluid simulation, and that fact alone seemed to

make it more memorable to participants than other exhibits. *How Mercury Affects the Body* was one of the only exhibits to use visual cueing with lights to highlight parts of the exhibit that needed the participant's attention.

The biggest surprise in the study was how much the participants enjoyed the historical displays inside the *Mercury Through the Ages* area of the VLE, *The Tomb of Qin Shi Huang* in particular. The exhibits inside *Mercury Through the Ages* were mostly static. The only real interactions were in opening the doors to the *Egyptian Tomb* and *Mayan Ball Court* exhibits and the ability for a participant to click on the ballcourt marker inside the Mayan exhibit, and move it to reveal a bowl of mercury. *The Tomb of Qin Shi Huang* did not have any interactive elements. Why would participants remember these exhibits in particular? An explanation could be that these three exhibits were the most immersive of the exhibits inside the VLE. If participants were inside any of the three historical exhibits, they could not see any other exhibit. One participant commented that "because they (historical exhibits) had dedicated environments to their display, it was more interesting to look at than one with just plain display cases." A second participant commented they remembered the historical displays best because, "they are fully immersive rooms."

## CHAPTER 4

### DISCUSSION

The purpose of this study was to evaluate whether the quality of 3D graphics had an effect on student learning and sense of presence inside a Virtual Learning Environment (VLE). With regards to the 3D graphics, the two areas of focus were: the shader fidelity and model fidelity.

In this study, there were no significant main effects findings of shader fidelity or model fidelity on either learner score or any presence subscale: sensory fidelity, involvement, adaptation/immersion or interface quality. In what follows, there is a discussion of each examined research question from the study, and explore possible reasons for the lack of significant findings.

#### Research Questions

**Question 1: To what extent does the use of high fidelity shaders (shaders that have had many attributes manipulated) in an Virtual Learning Environment (VLE) bolster scores on a measure of user presence, compared to a version of the VLE with low fidelity shaders (fewer attributes manipulated)?** Even though shader fidelity's effect on the presence subscales was not significant, sensory fidelity,  $F(1,72) = 1.136, p = .290, \eta^2 = .016$ , involvement,  $F(1,72) = 2.505, p = .118, \eta^2 = .034$ , adaptation/immersion,  $F(1,72) = 0.448, p = .505, \eta^2 = .008$  or interface quality,  $F(1,72) = .832, p = .365, \eta^2 = .003$ , a condition with high shader fidelity had the highest mean user score in three of the four presence subscales, including the highest two scores in the involvement subscale. In addition, no high shader fidelity condition ever received the lowest mean score in any of the subscales. However, the difference in mean scores between the high shader fidelity

and low shader fidelity conditions was not dramatic. The combined subscale mean scores are presented in table 10.

Table 10

*Combined Mean Scores for Shader Fidelity on Presence Subscales*

	Sensory Fidelity	Involvement	Adaptation/ Immersion	Interface Quality
High Shader Fidelity combined Means	17.29	53.13	41.16	16.27
Low Shader Fidelity combined Means	16.63	51.16	40.41	15.50

According to Whitelock (2000), higher presence leads to more engagement and more engagement leads to more time on task. The two high fidelity shader conditions look more visually appealing and that appeal could lead to more involvement or immersion, which are two of the presence subscales. Between the two high shader fidelity conditions, what could make the high shader fidelity/low model fidelity condition more generate higher presence scores is in smoother movement inside the VLE. With fewer polygons to redraw in the low model fidelity conditions, the VLE runs more smoothly, or to put it another way, with less lag, than the high model fidelity conditions. Lag has been mentioned by (Barfield & Hendrix, 1995) and (Barfield, Biard and Bjorneseth, 1998) as a factor that takes away from a participant's sense of presence. On the other hand, it is possible that time on task is acting as an alternative measure of user

presence, with higher visual fidelity versions of the VLE associated with significantly longer time on task outcomes.

**Question 2: To what extent does the use of high fidelity 3D models (more detailed/higher polygon count/smooth surfaces) in an VLE bolster scores on a measure of user presence versus the same environment using low fidelity models?** Data

gathered in this study showed that there was no significant main effect of model fidelity on any of the presence subscales. The results are as follows: sensory fidelity,  $F(1,72) = 1.528, p = .220, \eta^2 = .021$ . involvement,  $F(1,72) = 0.00, p = 1.000, \eta^2 = .000$ , , adaptation/immersion,  $F(1,72) = 0.578, p = .450, \eta^2 = .008$  and interface quality,  $F(1,72) = 1.212, p = .275, \eta^2 = .017$ .

There did not seem to be any indication that the use of high fidelity 3D models bolstered the scores on a measure of user presence versus low fidelity 3D models. A condition with low model fidelity had the highest mean score in three of the four presence subscales, including the highest two scores in the interface quality subscale. The only subscale where the high model fidelity scored higher than low model fidelity was in sensory fidelity. The combined subscale mean score for involvement was exactly the same between the high model fidelity and low model fidelity conditions. Even though the low model fidelity conditions had the majority of higher scores on the presence subscales the difference was not dramatic. Table 11 presents the combined mean scores for model fidelity for each subscale.

Table 11

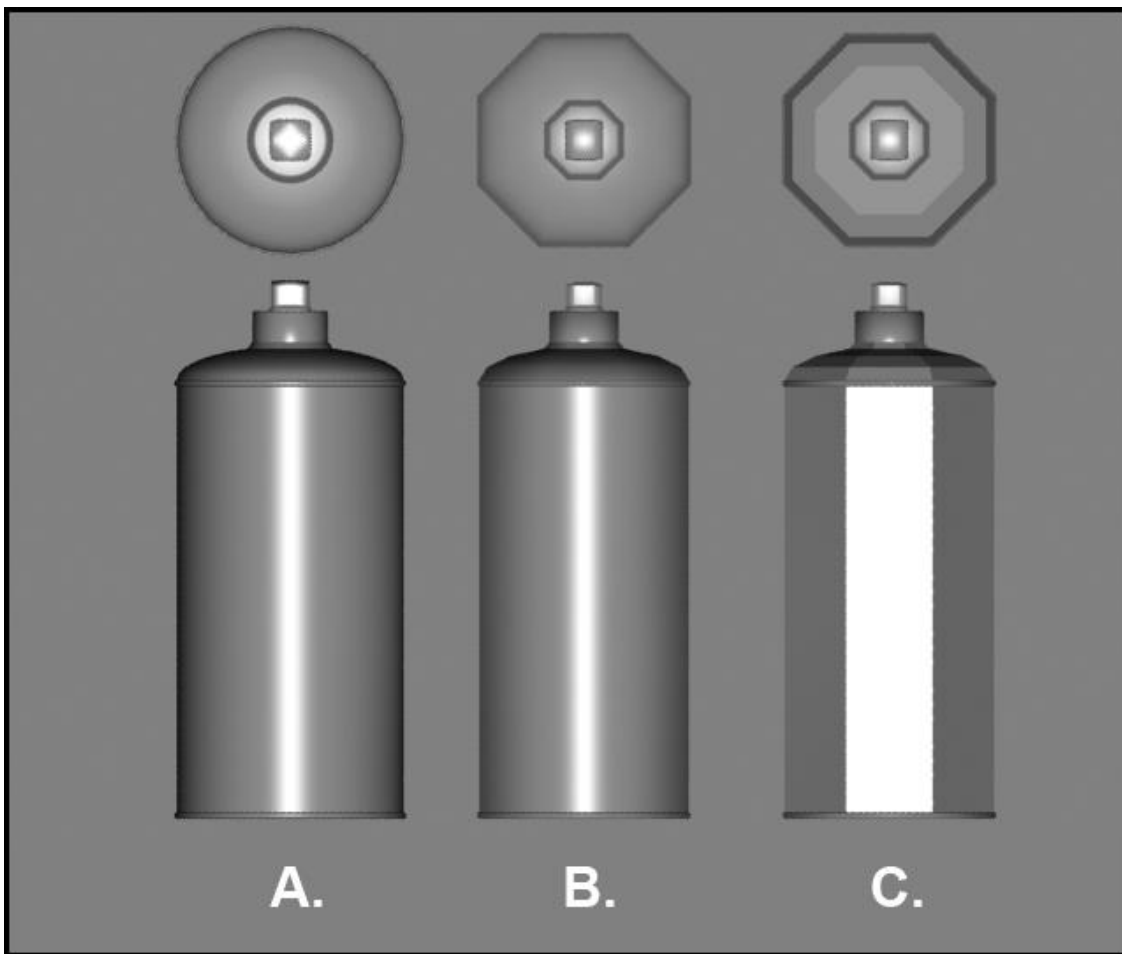
*Combined Mean Scores for Model Fidelity on Presence Subscales*

	Sensory Fidelity	Involvement	Adaptation/ Immersion	Interface Quality
High Model Fidelity combined Means	17.34	52.16	40.36	15.42
Low Model Fidelity combined Means	16.58	52.16	41.24	16.35

A possible explanation for the lower fidelity conditions having a higher average presence score is that when moving inside the VLE, it is difficult to focus on the shape of the 3D models. Only when the participant is not moving can they really look at the 3D model's shape. Since the participant is moving almost continuously inside the VLE, walking, jumping, looking around, the movement reduces the ability to see the detail or contours of the 3D models.

Another possible explanation is that there are many game industry techniques that can be used to make a lower polygon model look like a higher polygon model, such as smoothing groups. Smoothing groups indicate to the game engine how to shade the 3D model's surface. There are two options, smooth and faceted (think of a disco ball). If the 3D model's faces are set to smooth, even a very low polygon model can look smooth as long as you do not get a good look at the outside shape (silhouette) of the model. Figure 22 shows an example of how smoothing groups can hide a lower polygon count of a model. Model "A" is a high polygon fidelity model from the VLE. Model "B" is the

equivalent low polygon fidelity model with smoothing groups applied. From the front view, the two models look almost identical. It is only when you see the shape of the model from a top down view do you realize that model “B” has much less geometry and that the model has very little curvature around the circumference of the cylindrical areas. Model “C” is the exact same model as model “B” but without smoothing groups applied. Without the smoothing groups applied to model “C” the very blocky shape of the model becomes very apparent.



*Figure 22: Smoothing group effect on model surface*

Smoothing groups are typically enabled for primitive models like a sphere or cube. However, once the artist extrudes or bevels polygonal faces, the new faces do not have smoothing groups applied and thus look faceted. Since just about every model in the VLE had at least an extrusion or bevel, the use of smoothing groups was extensively used on both the high and low polygon conditions.

**Question 3: To what extent is the use of high fidelity shaders associated with increased learning inside a VLE versus a VLE that uses low fidelity shaders?**

As reported, shader fidelity had no significant main effect on learner score,  $F(1,72) = 0.20, p = .982, \eta^2 = .000$ . In fact, the low shader fidelity/low model fidelity condition, which of the four conditions is the least polished visually, was the one that recorded the highest mean learner scores  $M=75.0\%$ ,  $SD=9.45\%$ . In contrast to having the highest mean, the other low shader fidelity condition, low shader fidelity/high model fidelity, had the lowest mean learner scores  $M=67.7\%$ ,  $SD=18.8\%$ . The high shader fidelity conditions both had the same mean score of 70.8% with the high shader fidelity/high model fidelity having a slightly higher standard deviation ( $M=70.8\%$ ,  $SD=18.2\%$ ) than the high shader fidelity/low model fidelity ( $M=70.8\%$ ,  $SD=16.0\%$ ). From this experiment there does not appear to be any real evidence that the shader fidelity alone leads to higher learning scores, at least inside this particular VLE. This result is not surprising given previous studies such as Zimmons and Panter (2003) and Geudeke (2008) that showed that higher texture sizes of a shader, which is a factor in shader quality, had no impact on learning or task performance.

**Question 4: To what extent is the use of high fidelity 3D models associated with increased learning inside a VLE versus a VLE that uses low fidelity 3D models? As**



reported in the results, there was no significant main effect of model fidelity on learner score,  $F(1,72) = 1.001, p = .320$ , partial  $\eta^2 = .014$ . The two low model fidelity conditions had a higher mean learner scores, 72.9%, than the two high model fidelity conditions, 69.3%. The difference between the average of high model fidelity conditions and the low model fidelity conditions is 3.65% on a learning measure where the possible range of scores was 0-100%. The mean values for all four conditions of high and low model fidelity fell within a narrow range. The difference between the highest mean and the lowest was 7.3%.

A possible explanation for the lack of difference in mean scores between conditions is that the even though the low model fidelity conditions used far fewer polygons than the high model fidelity, the reduction didn't interfere with the participant's ability to interact, inspect, or read text on any 3D model inside the VLE. No models were reduced to the point where the information that could be gathered from that model or exhibit was any more difficult than in the high fidelity models condition. Therefore, the effect of more polygons being used on a model for learning may have been minimized.

**Question 5: Is there an interaction between shader and model fidelity that has an effect, positive or negative, on a learner's sense of presence inside a VLE?** There was no statistically significant interaction between shader fidelity and model fidelity on any of the presence subscales: sensory fidelity,  $F(1,72) = .307, p = .581$ , partial  $\eta^2 = .016$ , involvement,  $F(1,72) = .0529, p = .469$ , partial  $\eta^2 = .007$ , adaptation/immersion,  $F(1,72) = 2.934, p = .091$ , partial  $\eta^2 = .039$ , and interface quality,  $F(1,72) = 1.212, p = .275, \eta^2 = .017$ . Perhaps the lack of a significant interaction, or for that matter a significant main

effect, could be due to the lack of power in the study. There were only nineteen subjects per condition and with that sample size, it is difficult to see small effects.

**Question 6. Is there an interaction between shader and model fidelity that has an effect, positive or negative, on learning inside a VLE?** There was no statistically

significant interaction between shader fidelity and model fidelity on learner score

$F(1, 72) = 1.001, p = .320, \text{partial } \eta^2 = .014$ . The reason for this lack of interaction, like in the previous question, could come down to sample size. Maybe there was a significant interaction or some significant main effects of shader or model fidelity but the main effect was just too small to be detected with the existing number of samples per condition.

### **Supplemental Variables**

Two significant results were found when analyzing the secondary variables effect on the presence subscales and learner score. First, computer gameplay hours per week had a significant effect on learner score. Increased numbers of gameplay hours was positively associated with learner score. Secondly, gender had a significant effect on presence. Female participants reported a higher mean presence scores across all presence subscales than males.

The gameplay hours per week result is the less surprising of the two results. The results from this study are similar to previous studies by Enochsson, Isaksson, Tour, Kjellin, Hedman, Wredmark and Tsai-Fellander (2004) and Rosser, Lynch, Cuddihy, Gentile, Klonsky and Merrell, (2007). A possible explanation is that participants who have spent more hours playing computer games were familiar with the control configuration, reducing cognitive load and allowing them to focus their mental resources

on learning tasks inside the VLE rather than thinking about how to maneuver and interact inside the virtual environment. However, the significant results should be viewed cautiously. With a small sample size, six (6) in the case of the participants who played more than 15+ hours per week of , it is very possible that they are not indicative of the general population. So the significant result might not reflect a true effect.

The difference in presence by gender in this study was a bit surprising at first glance. However, a possible explanation could be found in the games that females tend to prefer. According to Phan, Jardina, and Hoyle (2012), female gamers prefer social, puzzle/card, music/dance type games along with adventure, driving and sports. One genre that was not mentioned was First Person Shooter (FPS) type game, in which the player is basically looking out of the game character's eyes. The FPS genre is one that typically has some of the most realistic looking graphics. With the exception of adventure and driving type games, genres like social, puzzle, card, music/dance type games tend to have more stylized, less realistic looking graphics. So when exposed to an FPS type game that looks more realistic, like in the experiment, the effect on presence and immersion might seem more pronounced because of the fact that the females are not as used to seeing the higher graphic fidelity. The males, who tend to play more of the action genre, which would include FPS type games, could be more sensitized to the higher graphic fidelity and thus the effect of high fidelity graphics could be lessened.

### **Attitudinal Discussion**

Overall, the attitudes of the participants were generally favorable across all combinations of shader fidelity and model fidelity based on the results of the attitudinal survey and interviews. The two main themes that stood out were that the interactive

nature of the virtual environment was a plus but the control system was not intuitive and a little hard to control.

The interactive nature of the virtual environment was a positive among the participants. By being able to interact with the virtual environment possibly made it more engaging to the participants, and took them from passive learning like reading from a book or listening to a lecture, to active learning.

The control system was a problem. Referring back to the presence questionnaire, and the fact that control is a component of presence, perhaps the control system took away some of the sense of immersion or presence for the participants because it was not as intuitive as it could have been. Just locking the cursor to a fixed point on the screen would have created some predictability or stability when interacting with the objects inside the virtual environment.

### **Limitations**

The primary limitation to the study was in the learning evaluation of the participants in the VLE. One of the primary components of learning in VEs is that the user can explore anywhere in the environment. Because of this freedom, no two participants will have the exact same learning experience inside the virtual environment. How can you evaluate learning with a high level of validity when each participant potentially has a different experience? A single learning measure was used, but there was no guarantee that all participants saw all exhibits related to all questions on the learning measure.

A second limitation could be the virtual environment itself. This was only the second virtual environment that I have designed and that inexperience in that area could

have contributed to lack of learning in some of the participants. A lot of thought was put into how the information was to be displayed, and there were many revisions to exhibits made during the construction of the virtual environment. Regardless if the way the information was displayed or presented made sense to the researcher, that does not mean that it will make sense to all of the participants. There were a number of changes made to the various exhibits in virtual environment based on feedback from the pilot test. If another round of pilot testing was conducted, there would probably have been another list of potential changes just as long as the first.

The curriculum itself also could be considered a limitation. The subject matter is not one that is specifically taught in science curriculum, so most of the material would be new to a participant. There were twenty questions on the learning measure with additional facts that were not the learning measure scattered throughout the virtual environment. To try and remember all of the facts on mercury will quickly fill up working memory and cause cognitive overload even with the use of notes. In addition, the average time spent in the VLE was just under thirty-two (32) minutes. A very short time to learn all of the information presented inside the VLE.

A final limitation to the study could be that there was no piloting specifically of the visual conditions to see if participants could readily see a difference between the high and low fidelity conditions. If participants could not see any difference, then perhaps the differences between the conditions may have been too subtle to notice.

### **Future research**

Even though the main effect of shader fidelity on presence was non-significant, there was a non-significant trend indicating that higher fidelity shaders may support a

higher sense of presence inside a virtual environment versus lower fidelity shaders. A future study with a much larger subject pool may have a better chance of detecting such a relationship. There is not much current research in the literature about the relationship between high fidelity shaders and presence in immersive learning environments, so it would be worth investigating further.

A second area for future research could be specifically looking into how much presence varies by gender inside a virtual environment, and why. In this study, gender was not the primary focus, so there was not any data gathering that was specifically addressed that topic. Slater, et al (2009) also had gender as a supplementary variable and it also was found to be significant factor in presence but that study also did not have any specific gender based questions related to presence levels.

A third area for future research could look into the effect of movement on visual fidelity inside a virtual environment. Investigating out how much graphical elements, 3D models and shaders can be downgraded before the player would notice, could be beneficial for developers since they are always constrained by the limitations of the hardware used to run the games.

One final area for research could investigate how layout of virtual environments affects presence. Could layouts that are somewhat closed, like the *Mayan Ball Court* or the *Tomb of Quin Shi Huag*, create a greater sense of presence to a participant than a more open layout?

### **Implications for the Field**

The results of this study seem to be consistent with much of the research on visual fidelity's impact on learning and presence in a virtual environment, in that the impact is

inconclusive. Visual fidelity might impact learning and presence but visual fidelity alone does not have a huge impact if at all. There are many factors in a virtual environment that influence both presence and learning inside the VE, such as the asset design, the interactivity, the user interface and the layout of the space. Future designers of virtual environments might be less concerned with the quality of the visuals since they, taken as an isolated variable, seem to have little impact on presence or learning. However, in regards to higher fidelity visuals of a virtual environment, the quality of the shaders seems to be more important than the quality of the models.

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APPENDIX A

COMMON ATTRIBUTES OF SHADERS

*Diffuse/Color:* Defines the surface color of the object in normal, full, white light. The normal color of an object is typically defined by its Diffuse color.

*Specular/Glossiness* refers to the color of the highlights where the light is focused on the surface of a shiny material and to the size of the highlights and how the highlight fades out.

*Transparency/Opacity* refers to the opaqueness or lack thereof of a surface. “Opacity refers to the amount that an object refuses to allow light to pass through it.”(Max Bible 2010, p. 392).

*Reflection* refers to how much a surface reflects the surrounding environment

*Refraction* is the bending of light as it moves through a transparent material.

*Bump/Normal Bump.* The bump attribute refers to using a texture map to “rough up” the surface features of a rendered object. It simulates areas of a surface that are raised or lowered, thus giving a surface a more realistic look. Bump maps do not change the shape of the underlying geometry.

*Displacement* is very similar to bump. It also uses a texture map to “rough up” the surface features of an rendered object. However displacement maps do change the actual shape of the underlying geometry.

APPENDIX B

DEMOGRAPHIC SURVEY

## Participant Demographics

1. Which category below includes your age (check one)? ☐ 18-19  
☐ 20-29 ☐ 30-39 ☐ over 40

2. Are you Male or Female?  
☐ Male ☐ Female

3. How much time do you spend playing computer games in a typical week?  
☐ none ☐ 1-5 hours ☐ 6-10 hours ☐ 11-15 hours  
☐ 15+ hours

4. How many virtual environments (Second Life, 3D MMORPGs, 3D simulations etc.)  
have you previously explored/played?  
☐ none ☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ 10 or more



## APPENDIX C

PRESENCE QUESTIONNAIRE BASED OFF OF WITMER & SINGER'S PRESENCE

QUESTIONNAIRE V. 4.0.

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

### WITH REGARD TO THE EXPERIENCED ENVIRONMENT

1. How much were you able to control events (movement, interacting with learning stations?)  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT AT ALL			SOMEWHAT			COMPLETELY
  
2. How much were you able to control events (movement, interacting with learning stations?)  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT RESPONSIVE			MODERATELY RESPONSIVE			COMPLETELY RESPONSIVE
  
3. How much did the visual aspects of the environment involve you?  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT AT ALL			SOMEWHAT			COMPLETELY
  
4. How much did the auditory aspects of the environment involve you?  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT AT ALL			SOMEWHAT			COMPLETELY
  
5. How much did your experiences in the virtual environment seem consistent with your real world experiences?  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT CONSISTENT			MODERATELY CONSISTENT			VERY CONSISTENT
  
6. Were you able to anticipate what would happen next in response to the actions that you performed?  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT AT ALL			SOMEWHAT			COMPLETELY
  
7. How completely were you able to actively survey or search the environment using vision?  

_ _	_ _	_ _	_ _	_ _	_ _	_ _
NOT AT ALL			SOMEWHAT			COMPLETELY
  
8. How compelling was your sense of moving around inside the virtual environment?

_	_	_	_	_	_	_
NOT			MODERATELY			VERY
COMPELLING			COMPELLING			COMPELLING

9. How closely were you able to examine objects?

_	_	_	_	_	_	_
NOT AT ALL			PRETTY			VERY
			CLOSELY			CLOSELY

10. How well could you examine objects from multiple viewpoints?

_	_	_	_	_	_	_
NOT AT ALL			SOMEWHAT			EXTENSIVELY

11. How well could you move or manipulate objects in the virtual environment?

_	_	_	_	_	_	_
NOT AT ALL			SOMEWHAT			EXTENSIVELY

12. How involved were you in the virtual environment experience?

_	_	_	_	_	_	_
NOT			MILDLY			COMPLETELY
INVOLVED			INVOLVED			ENGROSSED

13. How much delay did you experience between your actions and expected Outcomes (lag)?

_	_	_	_	_	_	_
NO DELAYS			MODERATE			LONG
			DELAYS			DELAYS

14. How quickly did you adjust to the virtual environment experience?

_	_	_	_	_	_	_
DID NOT			SLOWLY			LESS THAN
ADJUST AT ALL						ONE MINUTE

15. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

_	_	_	_	_	_	_
NOT			REASONABLY			VERY
PROFICIENT			PROFICIENT			PROFICIENT

16. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

_	_	_	_	_	_	_
NOT AT ALL			INTERFERED			PREVENTED

SOMEWHAT

TASK PERFORMANCE

17. How much did the control devices interfere with the performance of assigned tasks or with other activities?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐  
NOT AT ALL INTERFERED SOMEWHAT INTERFERED GREATLY

18. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐  
NOT AT ALL SOMEWHAT COMPLETELY

19. How completely were your senses engaged in this experience?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐  
NOT ENGAGED MILDLY COMPLETELY  
ENGAGED ENGAGED

20. How easy was it to identify objects through physical interaction inside the virtual environment; like touching an object, walking over a surface, or bumping into a wall or object?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐  
IMPOSSIBLE MODERATELY VERY EASY  
DIFFICULT

21. Were there moments during the virtual environment experience when you felt completely focus on the task or environment?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐  
NONE OCCASIONALLY FREQUENTLY

22. How easily did you adjust to the control devices used to interact with the virtual environment?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐  
DIFFICULT MODERATE EASILY

## APPENDIX D

### LEARNING MEASURE ON THE SUBJECT OF MERCURY

Directions: For the following multiple choice questions, please circle the answer that you feel

is most correct for the following questions.

1. Mercury has been found in Egyptian tombs as old as?
  - a. 3500 B.C.
  - b. 3000 B.C.
  - c. 2500 B.C.
  - d. 1500 B.C.
  
2. The symbol for mercury on the periodic table of the elements is?
  - a. Me
  - b. Mr
  - c. Hg
  - d. He
  
3. Mercury can occur in both elemental form (liquid) and in compounds. Which of the following forms of mercury is the most toxic/dangerous?
  - a. Elemental form
  - b. Dimethylmercury
  - c. Mercuric oxide
  - d. Mercuric sulfide
  
4. Mercury is mined in all of the following countries **except:**
  - a. Spain
  - b. Kyrgyzstan
  - c. Algeria
  - d. Portugal
  
5. Which of the following statements Mercuric Properties (weight, color, conductivity, etc.) is **not** true?
  - a. Mercury is a conductor of electricity
  - b. Mercury boils at 674.11 F
  - c. Mercury is magnetic or can be magnetized
  - d. Mercury freezes at - 37.89 F
  
6. All of these common products have mercury in them **except:**

- a. Thermometers
  - b. Smoke Detectors
  - c. House Paint
  - d. Dental Amalgams
7. Mercury is extracted primarily from this material?
- a. Cinnabar
  - b. Zanzibar
  - c. Calcite
  - d. Linarite
8. Mercury can enter your body by a number of methods. Which method would expose a person to the highest toxicity level the quickest?
- a. Drinking mercury
  - b. Contact with an open wound/cut
  - c. Inhaling mercury vapor
  - d. Eating fish contaminated with mercury
9. “**Bioaccumulation**” refers to:
- a. The gradual increase of mercury concentration in a geographic region
  - b. The gradual increase of mercury concentration in the food chain
  - c. The gradual increase of mercury concentration in insects
  - d. The gradual increase of mercury concentration in the atmosphere
10. In the event of a small mercury spill you should do all of the following **except**...
- a. Vacuum up small droplets of mercury
  - b. Use an eyedropper to pick up small droplets of mercury
  - c. Use adhesive tape to pick up small droplets of mercury
  - d. Open the windows or doors in the area
11. Mercury was found in excavated buildings/structures of all of the following societies **except**:
- a. Mayan
  - b. Chinese
  - c. Incan
  - d. Egyptian

12. Mercury is known to chemically react and dissolve metals. Which of the following does it not react with?
- a. Silver
  - b. Copper
  - c. Gold
  - d. Iron
13. Mercury gets into the oceans, and thus into the marine ecosystem, by one primary means. What is it?
- a. Evaporated mercury combines with atmospheric moisture and is deposited in the rain
  - b. Ocean floor volcanic activity
  - c. Artesian Gold mining
  - d. Fuel combustion
14. How does mercury become *methylmercury*?
- a. Exposure to high temperatures
  - b. Exposure to low temperatures
  - c. Exposure to bacteria
  - d. Exposure to digestive enzymes
15. At the Ruins at Lamanai, where was the container full of mercury found?
- a. Under the sacrificial altar at the top of the Pyramid
  - b. Inside the king's throne room
  - c. Under the game marker at the center of the ball court
  - d. Inside the shaman's quarters
16. If you dropped a 20lb cannonball made of iron into a pool of mercury, what would the result be (besides a splash)?
- a. The cannonball would float
  - b. The cannonball would sink
  - c. The cannonball would dissolve
  - d. The cannonball would explode
17. In today's society, the greatest amount of mercury (as measured by weight) is used for the following product?
- a. Dental amalgams (fillings)
  - b. Energy efficient light bulbs



- c. Electrical switches and relays
- d. Disposable batteries

18. The atomic number of mercury is?

- a. 78
- b. 79
- c. 80
- d. 81

19. Which modern chemist is responsible for the modern understanding of mercury?

- a. Antoine Lavoisier
- b. Louis Pasteur
- c. Edward Munch
- d. John Dalton

20. Which of the following organisms would likely have the highest bioaccumulation of mercury in an ecosystem?

- a. Phytoplankton
- b. Zooplankton
- c. Small forage fish
- d. Large predatory fish

APPENDIX E

PARTICIPANT ATTITUDE SURVEY

Directions : Please circle the answer that best describes your opinion.  
**Attitudes towards the Virtual Learning Environment (VLE) (The environment focused on Mercury).**

**Motivation/Intention**

1. I feel the VLE made me concentrate more while learning.

1 2 3 4 5 6 7

Strongly Disagree

Strongly Agree

2. I think the use of VLEs can strengthen my intentions to learn about mercury versus traditional classroom presentation and experimentation.

1 2 3 4 5 6 7

Strongly Disagree

Strongly Agree

3. The VLE was an engaging way to learn about mercury

1 2 3 4 5 6 7

Strongly Disagree

Strongly Agree

4. I was motivated to try all of the various learning stations.

1 2 3 4 5 6 7

Strongly Disagree

Strongly Agree

5. I would use a VLE to learn about additional subjects in the future.

1 2 3 4 5 6 7

Strongly Disagree

Strongly Agree

6. Overall, I think VLEs are good learning tools.

1 2 3 4 5 6 7

Strongly Disagree

Strongly Agree

**Opened ended questions**

7. Name one fact about mercury that stands out the clearest in your mind?
  
  
  
  
  
  
  
  
  
  
8. Which learning station or information board stands out the clearest? Why?

Thank you for your participation in this study!

APPENDIX F

INTERVIEW QUESTIONS

What did you think of the Virtual Learning Environment (VLE)?

What was the best part of the VLE?

Was could have been improved in the VLE? Visually? Technically? If anything?

## APPENDIX G

### DESIGN DOCUMENT FOR VIRTUAL LEARNING ENVIRONMENT

## **Virtual Learning Environment (VLE) Overview**

The Virtual Learning Environment, from this point forward known as “VLE” is a 3-D rendered world based on contemporary interactive science centers full of different exhibits that can be both interactive and informative at the same time.

The VLE’s primary function is to allow a participant to learn about the element mercury (Hg). A second primary goal is to make this VLE interesting to the participant in order to increase motivation, engagement and time on task, all of which increase learning. This goal will be achieved by making the VLE both interactive and visually interesting.

### **Platform**

The VLE will utilize the PC as the platform with the Unreal Development Kit (UDK) as the game engine that will allow the rendering of the game world and the interactivity.

### **Genre**

This VLE will fall under the genre of educational games, though it is not per se a game but a virtual learning environment. There will be no in game score or stated objectives beyond learning about mercury through interaction with the virtual world.

### **Core Gameplay**

### **Game Mechanics**

The mechanics of the game will be similar to contemporary First Person Shooters (FPS). Using the mouse and keyboard, the participant will move around the VLE by the default keyboard and mouse controls that are utilized by UDK. The main movement controls are as follows:



Keyboard Key	Function
A	Move Left
D	Move Right
W	Move Forward
S	Move Backwards
E	Interact/Action with VLE objects
Spacebar	Jump
Move mouse	Look around
Left mouse button click	Interact with VLE objects

Although some exhibits and objects, like doors, will react to the participant as they approach, the primary means of interacting with the various exhibits will be by left clicking the mouse cursor on buttons or controls . The left click will allow the participant to press buttons, pull levers or open certain objects within the VLE.

### **Virtual Learning Environment Description**

The VLE is loosely based on contemporary science centers. Large, wide open interior spaces filled with many exhibits of various shapes and sizes that present a participant with information on a variety of subject matter (see image 1). The participant will be free to roam about in this environment inspecting and interacting with the various exhibits and learning stations, each of which will give the participant a bit of information on the element mercury. Being based on a real world environment and scale keeps the space feeling “real” but a strength of VLEs is that they can provide participants with experiences that would not normally be able to experience. This VLE environment allows for some bending of reality, as

in the case of fish swimming through the air, and what could be safely included in an exhibit, like generating lightning, in the exhibits.

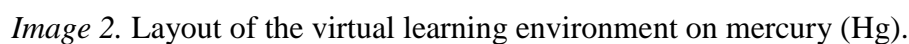


Image 1. Exhibit setup in the Arizona Science Center.

Informationally, the VLE is broken up into six main sections:

- 1) Properties of Mercury
- 2) Mercury in our Everyday Lives
- 3) Dangers of Mercury
- 4) How Mercury is Mined
- 5) Mercury through the Ages
- 6) Mercury in the Oceans

Virtual Learning Environment\_Mercury\_v1  
Horton



## 113

The VLE is broken down into six categorized learning areas. Each learning area has a number of static and interactive exhibits, each containing information about the element mercury. The contents of each learning area is broken down below.

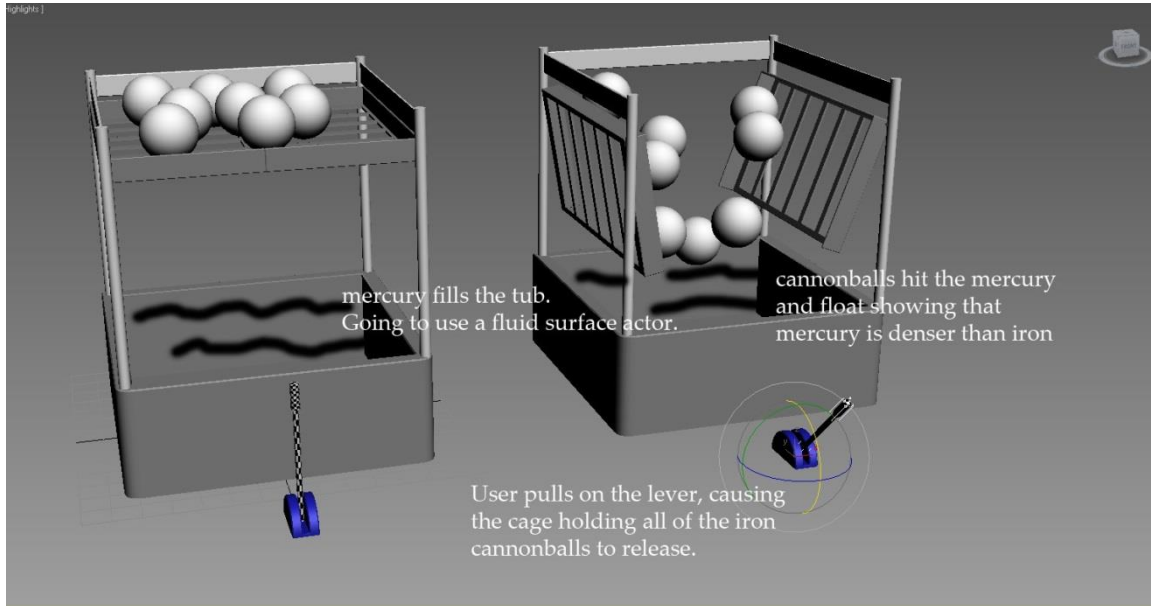
### **Properties of Mercury**

#### Interactive Exhibit(s)

##### Mercury Dunking Station

Description: The purpose of the station is to show that mercury is very dense relative to water and iron. Denser than iron and most definitely denser than water. The station itself, has a rectangular shaped base in which half is filled with mercury and half is filled with water. There will be a divider that separates the two halves. Above the pools, held aloft by support poles at each corner of the exhibit is a set of trap doors. On top of the doors is a number of steel cannonballs. On the ground in front of the exhibit is a pull handle. There is also an information board on the wall beside the exhibit that provides information on cannonballs. A prototype model of the station is pictured in image 3.

Actions: The participant will approach learning station. The pull handle will flash, indicating that the user is supposed to interact with it. When the participant pulls the handle, the cannonballs drop into the mercury and water of the learning station. When the cannonballs hit the mercury, instead of sinking, they float because iron is less dense than mercury but the cannonballs will sink because iron is denser than water.



*Image 3. Prototype design of the mercury dunking station*

### **Is Mercury Magnetic?**

**Description:** Exhibit will be used to determine if mercury is magnetic. This exhibit has a rough grey base with a graphic of a magnet on either side. The top of the exhibit has a clear acrylic glass over it. Inside the glass is a large, stylized magnet on a set of black rails. Under the magnet is a pool of mercury and a few steel nails. There is one button with a magnet on the front face of the exhibit cabinet. This exhibit is about the size of a classic arcade game.

**Actions:** The participant walks up to station. When participant enters trigger range, the magnet will slide along the black rails at the top of the station from either the left or right side of the rail to the center of the rail. This animation will take about 1.5 seconds. There

is both a pool of mercury and a few nails under the magnet. When the user mouses over the button on the front face of the exhibit it will light up indicating that they are supposed to click. Once the button is clicked, an animation plays of the nails moving from the top surface of the station up to the magnet and sticking there, but the mercury will not be affected because mercury cannot be magnetized. When the user clicks again, there will be a second animation played of the nails dropping back to the top surface of the station.

### **Katy Perry's Hot and Cold about Mercury**

Description: There are two interactive exhibits along with a title and information board in this exhibit. Using a play of Katy Perry's song Hot and Cold, the two interactive exhibits allow the participant to examine the boiling and freezing points of mercury. Katy Perry is used in both the title board and there is a large cut out located next to the exhibit in which Katy shouts, using comic book style language bubbles, about the boiling and freezing points of mercury and urges the participant to try out the exhibits.

### **Boiling point exhibit**

The boiling point exhibit has a rough grey base and the top of the exhibit has a clear acrylic glass over it. There is a vent sticking out of the glass to take away the dangerous mercury vapors that are created when boiling mercury. On top of the base, there is a large bowl that holds a blob of mercury and a burner underneath the bowl to heat the mercury up. There are three (3) buttons on the exhibit that the user can press, vent, hotter and off.

Actions: The participant walks up to the station and enters the trigger zone. There are three (3) buttons on the station that the user can press, vent, hotter and off. The vent button could

be flashing to cue the participant that they need to press it. Once pressed the vent button stops flashing and a sound plays of a fan whirling.

The hotter button, when pressed, will cause a particle system of fire to shoot upward from the burner, located under the bowl in the learning station. I'd also like pressing the hotter button to control a temperature gauge. Every time you press the hotter button the gauge would go up say 100 degrees until you hit the boiling point of mercury and then it would stop and flash that particular temperature. Do you know how to control a 2D movie with matinee/kismet? If not, I think I can throw something together in max that does the same things.

The off button turns off the heat. Add another particle system that looks like it is spraying cold/ice like particles to cool the station down. The temp gauge will go from where it is back to zero.

### **Freezing Point exhibit**

The Freezing Point exhibit also has a rough grey base and an acrylic top to it. On top of the base there is a plate with a blob of mercury in it. There are also two spouts jetting up from the base that point directly at the mercury. On the front panel of the exhibit there are two buttons one to freeze the mercury and the other to thaw it.

Actions: The participant walks up to the station and enters the trigger zone. There are two (2) buttons on the station that the user can press freeze and thaw. The blob of mercury shimmers and moves on the plate indicating that it is not frozen. Similar to the workings of the Boiling point station, the participant will press the freeze button to discharge a freezing spray from the spout onto the mercury. In this case a few presses will allow for

the freezing of mercury at -38.52 degrees Fahrenheit. Upon freezing the shimmering will stop and the mercury will appear frozen. The thaw button will basically do the reverse of the freeze button. It will shoot out a flame like particle and that will turn the mercury back to liquid where it will begin to shimmer again.

### **Static Exhibit(s)**

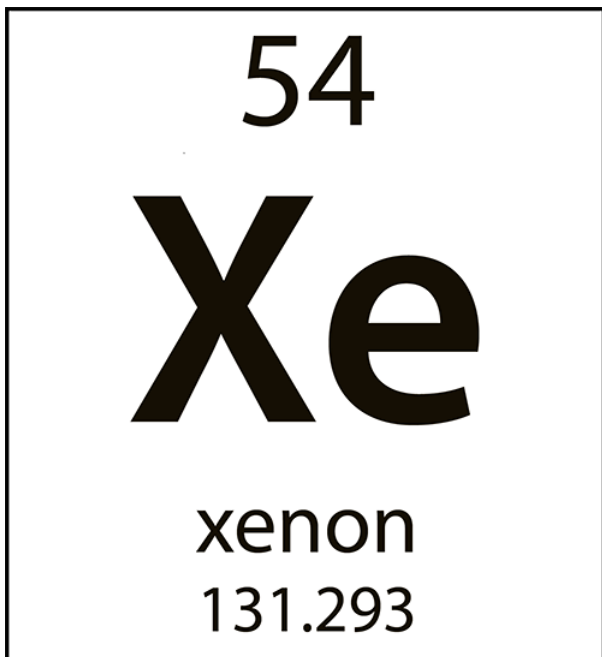
#### **Why is the Symbol for Mercury Hg?**

This wall mounted information board has a Socrates like talking head asking the above question of “Why is the Symbol for Mercury Hg?” The board displays for the participant the reasoning for using the Hg symbol instead of something more phonetically appropriate like Me.

#### **Large Periodic Table Symbol for Mercury**

This wall mounted information board is an oversized example of a typical periodic table square for an element (see image 4). The information board contains all of the typical information like: atomic symbol, atomic number, atomic weight etc. The components will all be labeled for the participant.





*Image 4.:* example of an periodic table element square

## **Mercury in Our Everyday Lives**

### **Interactive Exhibit(s)**

#### **Disposable Battery Exhibit**

Description: The exhibit is broken down into two parts, two information boards that are mounted on the wall and a table stand in which the upper portion is covered by a curtain.

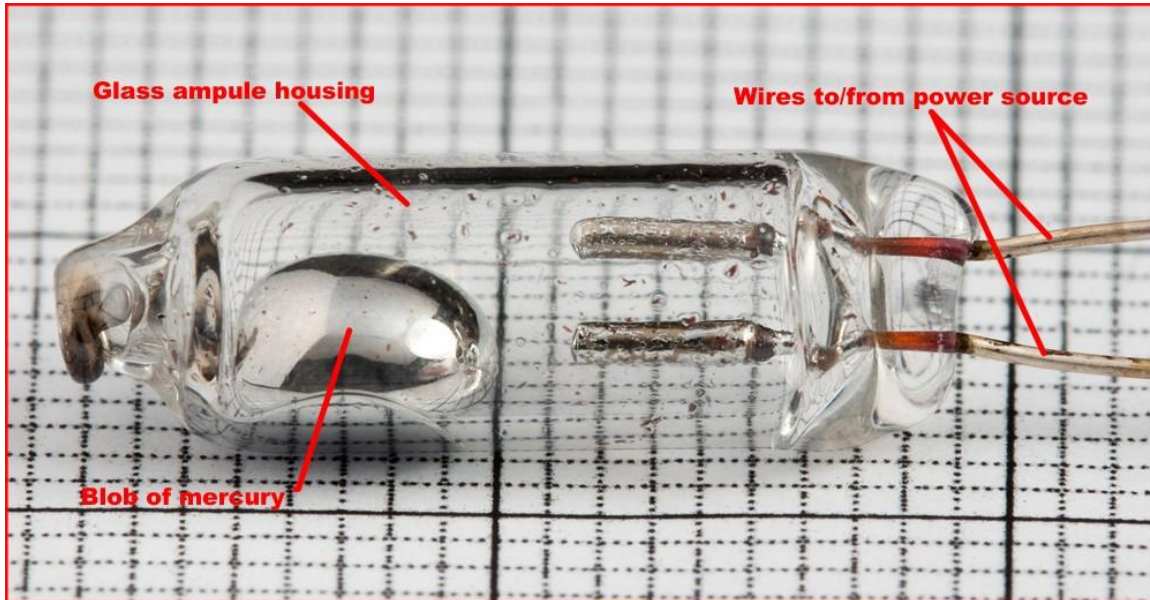
The primary information board contains a bar chart of consumer products that use mercury (in tons used). This primary information board displays only products 2-6 in tons of mercury used. On the smaller, secondary board there is a button with a caption that reads “Push Button to reveal #1” which refers to the product in which the most mercury is used during manufacturing.

Actions: The participant will approach the information board and left mouse button click (LMB) on the button. This action will cause the curtain to raise up towards the ceiling, revealing a disposable battery, which is the product that uses the most mercury during manufacturing annually.

### **Mercury Switch/Chest Freezer**

Description: The exhibit has three components: two information boards that are mounted on the wall, a chest freezer that is closed and an oversized mercury switch and light bulb that is also mounted on the wall. An example of the components of a mercury switch are in image 5 below.

Actions: As the participant approaches the learning station, the chest freezer material will flash from normal to yellow indicating that it should be interacted with in some way. When the participant LMB clicks on the freezer, the lid will open. Concurrently, the oversized mercury switch on the wall will also tilt illustrating that the switch tilts when the freezer door opens. Inside the glass ampule of the mercury switch, the mercury will be animated moving from one side of the ampule to the other. When the mercury covers the tips of the wire, the light bulb will turn on.



*Image 5. close up of mercury switch glass ampule*

The two information boards provide information about how a mercury switch works and why mercury is used as the material in the switch.

### **Mercury in Your Mouth**

Description: The Mercury in Your Mouth exhibit is made up of two pieces: a oversized upper and lower set of teeth and gums and an floor stand that displays information on mercury amalgam fillings, what the fillings are made of, how many fillings are currently in people's teeth, etc.

Actions: As the participant approaches the exhibit, there is no clickable button or object to trigger the interactivity. The participant only has to get close enough to read the floor stand and a proximity trigger will be tripped and the mouth will open. A sound cue of "Aaaaaaahhhh..." will also play to get the participant's attention in case they are still reading the floor stand info.

### **Static Exhibit(s)**

#### **Paint Can Exhibit**

Description: The exhibit is composed of two static parts: a pyramid of paint cans and a floor mounted informational board that discussed why mercury was used in paints and a cautionary example of house paint causing mercury poisoning.

### **Dangers of Mercury**

#### **Interactive Exhibit(s)**

##### **How Mercury Affects the Body**

Description: In this interactive exhibit, the participant will learn how mercury negatively affects different parts of the body. This exhibit consists mainly of an acrylic human body on a rotating pedestal, in which the participant can see some internal structure such as organs and the nervous system (see image 6). There is also a series of floor triggers that are labeled with a body part or organ.

Actions: When the participant steps on the trigger, the body part or organ lights up on the rotating body. In addition, a acrylic informational sign drops from the ceiling in front of the participant, explaining how mercury affects the particular body part.



*Image 6. Acrylic anatomy model*

### **Inhale/Cleanup Exhibit**

Description: The Inhale/Cleanup Exhibit is two exhibits in one. The exhibit purpose is to answer two questions about mercury. Overall, the exhibit is “L” shaped if viewed from above and around 6’ tall. On one side of the exhibit a cartoon character poses the question “How can your body most quickly absorb mercury?” and on the other side “What should you do in the event of a mercury spill?” There are a series of doors on each side of the exhibit that have options that have the right or wrong answers to the above posed questions. Each of these doors is illustrated with the cartoon character performing the

action along with descriptive text.

Actions: The participant approaches the exhibit and reads the questions. They then can click on the doors of the exhibit. When they click on the door, it will pop open revealing whether their choice for an answer is correct or incorrect. A squeaky door sound will play as each door opens providing some feedback to the character that an action has happened. Either a buzzer (incorrect answer) or a bell (correct answer) rigging will accompany the answer also providing feedback to whether it was a correct or incorrect answer.

### **Static Exhibit(s)**

#### **Mad Hatter Information Board**

Description: This is a wall mounted information board that poses the question of “What made the Hatter mad?” The character being referred to is the “Mad Hatter” from Alice in Wonderland.

The text on the information board explains that mercury was commonly used to process felt, which was often used in 18th century hat making and inhaling the mercury each day caused the hatmakers to suffer from symptoms of mercury poisoning.

#### **Karen Wetterhahn and Dimethylmercury**

Description: This floor mounted information board displays a case study of researcher Karen Wetterhahn, and how a derivative of mercury called dimethylmercury killed her not long after exposure.

## **How Mercury is Mined**

### **Interactive Exhibit(s)**

#### **How Mercury is Extracted from Cinnabar**

Description: In this exhibit, the participant will learn how mercury is extracted from cinnabar. This exhibit will be located in a faux “mine” where the walls will look like rock (see image 5). This exhibit consists of a series of machines that will be animated that grind, crumble, vaporize and then condense the mercury out of the cinnabar. There will also be informational boards above the machines that describe what is happening during the extraction process. The machines will all be located on top of display table, on which reads “Extracting Mercury from Cinnabar.”

#### **Which Countries Mine Mercury**

Description: This floor mounted information board displays information on the three countries that mine the most mercury along with maps indicating where the country is geographically in the world. There are also flags of each country that are animated with the UDK cloth solver so they billow and move as though wind is blowing gently.

#### **Artesian Gold Mining**

Description: This is a five panel, wall mounted display that provides information on artesian gold mining operations, which are typically independent, small scale mining operations that use rudimentary methods to extract and process minerals. One of the methods used to recover metals and gems is to use mercury in the extraction process. The four images displayed on the four, non text boards show a plastic bagged portion of

mercury, heating up metals and mercury in a pan, a gold and mercury amalgam nugget and the primitive conditions at the mining site.

### **Iron Container for Mercury**

Description: This exhibit is an oversized iron container, like a jug on top of a stand and a small floor mounted information board on why iron is used to transport and hold mercury versus other types of container.

## **Mercury through the Ages**

### **Interactive Exhibit(s)**

#### **The Mayans**

Description: This is the first of three larger historical exhibits that detail how mercury was used and revered in ancient societies. The Mayan exhibit is a scaled down version of the Mayan ball court that was uncovered at Lamanai (image 6) , which is in modern day Belize. There are spectator stands on each side of the court made out of stacked stone. There are trees and grasses growing from both around the stands and on top of the stands. Jungle noises can be heard while standing in the exhibit. The centerpiece of the exhibit is a replica of the goal marker that was used during the ceremonial ball game that the Mayans used to play. As the participant moves towards the goal marker, it will slide to the side revealing a hole in the ground. Inside the hole in the ground will be a container of mercury. The small floor stand next to the marker will display information on the fact that during the excavation of Lamanai, mercury was found under the goal marker on the ball court.



## **Static Exhibit(s)**

### **The Alchemists**

Description: This exhibit is made up of several elements, some moving, some static. The static elements consist of two wall mounted information boards that discuss the seven metals of alchemy and how the alchemists came up with the modern name of mercury for use with the element. There is also a display table with bars of each of the seven metals of alchemy along with a recessed pool of mercury in the middle of the table. There are two banners, one on each side of the display tables, that move and flow as if there is wind displacing them. The two banners are for decorative purposes and contain no additional information on either alchemy or mercury.

### **The Tomb of Qin Shi Huang**

Description: This exhibit is for the Chinese Emperor Qin Shi Huang. Qin Shi Huang was an important figure in Chinese history but is noteworthy for dying of mercury poisoning and for being buried in a tomb in which there were moats of mercury.

Actions: Around the tomb, there is Chinese based artwork, a central, gold tomb, the moats of mercury along with two small floor mounted informational stands. The first stand, in the entryway to the tomb provides information on who and when the tomb was discovered. The second stand, near the gold coffin, provides information on Qin Shi Huang, specifically about how he died. The participant is free to move in this room sized exhibit. The participant will have to jump over the moats of mercury which is inset into the floor area.

## **The Egyptians**

Description: The Egyptian exhibit is a mock up of a hallway from an unnamed Egyptian structure. The participant enters through two large doors with Egyptian artwork decorating them. Behind the doors, there is a passage or hallway that has block columns on both sides with Egyptian hieroglyphs and freezes on the surfaces. Toward the back wall of the display there is a small floor mounted display that provides information to the participant specifically on the fact that mercury was found in Egyptian tombs as far back as 2500 b.c. There will be a knocked over container on the floor next to the informational stand with a large puddle of mercury.

The participant is free to move in this room sized exhibit. This exhibit is mostly for visual interest in that the only information it provides, as mentioned earlier, is that mercury was found in Egyptian tombs as old as 2500 b.c.

## **Mercury in the Oceans**

### **Interactive Exhibit(s)**

#### **How Mercury Enters the Water**

Description: This exhibit consists two parts: a table mounted display and a small, floor mounted display. The table mounted display consists of a landmass near a waterway/coastal area with a factory and a volcano set on top of the mass. Thick smoke emits from both the factory and the volcano, and the smoke rises up into the cloud mass that is sitting above the exhibit. Rain is falling from the clouds back down on the ocean and land. The floor mounted display provides information on the two primary means that mercury ends up in

the ocean (manufacturing and volcanic activity). There are a series of buttons on the floor mounted display that allow the participant to turn on/off any of the particle effects that control the atmospheric conditions, like rain and smoke, and the emitted smoke from the factory and volcano.

Actions: The participant will approach the display and floor mounted display stand. Once within the active area of the display trigger, the participant will read the floor mounted information display and reads about the two ways in which mercury enters the water. They will also be able to press the four buttons on the display that will toggle on/off any of the particle effects that control the atmospheric conditions, like rain and smoke, and the emitted smoke from the factory and volcano.

### **Bioaccumulation**

Description: The Bioaccumulation exhibit consists of two main parts: a mini section of an ocean, complete with animated fish of various sizes swimming around and an information display that explains how mercury is passed up the food chain and accumulates the larger predators in the food chain through a process called “bioaccumulation.”

Actions: The participant will approach the exhibit, attracted by the movement of the fish elements. As the participant nears he/she will hear wave sounds to enhance the ocean/waterway theme. The fish size will go from small, near the ocean “floor” in the lower part of the display to large in the higher area of the display. This size change will mimic the positioning of the text on the information board. The fish themselves will all

have a marker on them that represents mercury. The small fish have a single marker, while the medium ones have 3-5 and the larger ones have 7-9 markers. Each marker indicates how much mercury is in each type of fish. The participant can move through the exhibit but there is nothing to LMB click on or actively touch.

### **Static Exhibit(s)**

#### **Is it Safe to Eat Fish?**

Description: There are two floor mounted information boards that display information of a case study answering the question of “Is it safe to Eat Fish?” The case study involves a University of Rochester study conducted in the Republic of the Seychelles, in which the majority of the population eat a dozen seafood dishes a week and in turn has mercury levels in their bodies at a rate of 10x a typical person in the United States.

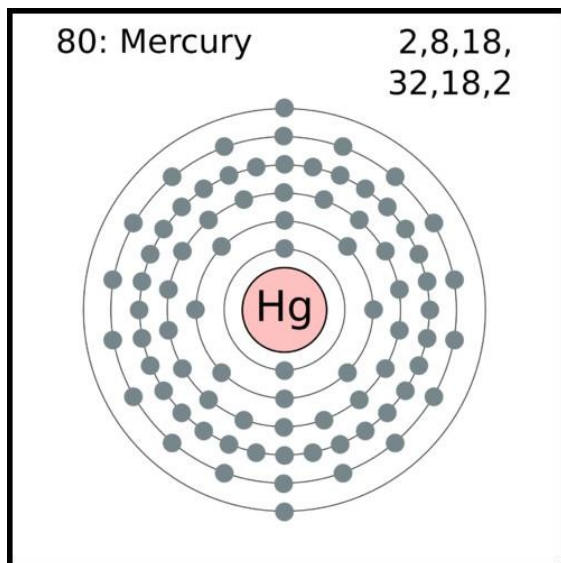
### **Miscellaneous Displays**

#### **Interactive Exhibit(s)**

##### **Mercury Electron Shell Diagram Mobile**

Description: This is a oversized, animated 3D version of an electron shell diagram of mercury. An electron shell diagram is a stylized illustration depicting how many electrons are in the various orbital rings around a nucleus of an atom. One is presented in image 6. There is also a small floor mounted display stand that provides information on the structure of a mercury atom with regards to the number of electrons in each shell. This will be the first display that the participant will see as they enter the VLE. On the

exhibit the various rings of electrons are spinning around the center of the exhibit. As the participant nears the exhibit and floor stand, a trigger that is located there will stop the electron rings from spinning so the participant can view the rings and verify that the number of electrons in each ring matches the number displayed on the information stand if he/she wants to count.



*Image 6. Electron shell diagram of mercury*

### **Static Exhibit(s)**

#### **Anotine Lavosier**

Description: This wall mounted exhibit consists of three static panels on the French scientist Anotine Lavosier. There a smaller rectangular panel that has his name, a very large circular picture of Lavosier and finally another smaller rectangular panel that has information on Lavosier's connection to mercury.

#### **Mikhail Lomsonov**

Description: Almost identical to the Lavosier display, but with a smaller picture, his wall mounted exhibit consists of three static panels on the Russian scientist Mikhail Lomsonov.

There a smaller rectangular panel that has his name, a very large circular picture of Lomsomov and finally another smaller rectangular panel that has information on Lomsonov's connection to mercury.

APPENDIX H

PILOT TEST QUESTIONNAIRE

**Transitional Environment**

1. The transitional environment (classroom) prepared me for moving inside the virtual learning environments.

1	2	3	4	5	6	7
Strongly Disagree					Strongly Agree	

2. The transitional environment (classroom) prepared me for interacting inside the virtual environments.

1	2	3	4	5	6	7
Strongly Disagree					Strongly Agree	

3. It was easy to move around the transitional environment.

1	2	3	4	5	6	7
Strongly Disagree					Strongly Agree	

4. It was easy to interact (pick up objects/ press buttons) inside the transitional environment.

1	2	3	4	5	6	7
Strongly Disagree					Strongly Agree	



## **Main Virtual Environment**

### **Objectives**

1. Describe the learning objective of the main virtual environment.
2. Was the objective clear at all time?

### **Controls**

3. Was the control scheme for moving and interacting intuitive?
- 4.. How well could you concentrate on interacting in the virtual environment rather than on the controls (**1** = Controls made it hard to concentrate on interacting in the virtual environment, **7**= Controls made it easy to concentrate on interacting in the virtual environment)?

1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7

5. Is there anything that you would change about the controls and the interface?

### **Learning Stations**

6. Was it unclear what the point of a learning station was? If so, which ones?
7. Was it unclear how to interact with any of the learning stations? If so, which ones?

### **Visuals**

8. Were any graphics unreadable because of size, clarity of type/text, placement within the environment? If so, could you describe which ones?
9. Did the virtual environment seem like a believable space? Why?
10. Did any aspect of the the virtual environment seem unbelievable? Why?
11. Do you feel anything was missing from the space that would make it seem more real? If so, what?
12. Can you suggest any improvements to the virtual environments?

APPENDIX I

LEARNING OBJECTIVES BY AREA

### **Properties of Mercury**

1. From a list of symbols, the participant can identify the Periodic/chemical symbol for mercury.
2. From a list of numbers, the participant can identify the Periodic/chemical number for mercury.
3. After exiting the VLE, the participant will understand the density of mercury relative to other elements in the periodic table.
4. After exiting the VLE, the participant will know the boiling and freezing points of mercury.
5. After exiting the VLE, the participant will know if mercury can be magnetized or is affected by magnets.
6. Given several choices, the participant will know why the Periodic/chemical symbol for mercury Hg and what it means..

### **Mercury in our Everyday Lives**

1. Given several options, participant will know which common household products have mercury in them.
2. From a list of household products, the participant will know which product accounts for the largest amount of mercury pollution in landfills.
3. Given several numerical values, the participant will know how many tons of mercury per year are used in mercury amalgam fillings.
4. After viewing an example mercury switch, participant will know how a mercury switch works.

5. Given an example of how a mercury switch works, participant will know if mercury is a conductor of electricity.

### **Dangers of Mercury**

1. Given different medical conditions, identify which are symptoms of mercury exposure.
2. From a list of procedures, identify which procedures are valid in case of a mercury spill.
3. Given different pathways into the body, understanding in which way a person can be exposed to mercury and which exposure method is the most dangerous.
4. From a list of mercury derivatives, participant will identify which derivative is most lethal.

### **How Mercury is Mined**

1. Given a list of several countries, identify which countries mine the majority of mercury.
2. Given several mined ores/elements, identify from which ore/element is mercury extract from most often.

### **Mercury through the Ages**

1. Given several ancient civilizations, participant will be able to identify several civilizations in which mercury was found at archeological sites.
2. From a list of dates, participant will identify at what point in history that mercury was used in Egyptian society.
3. From a list of several possible locations, know which ancient societies used mercury in their rituals.
4. From a list of metal elements, identify which elemental metals were part of the seven metals used in Alchemy.

**Bioaccumulation**

1. Given several definitions, participant will be able to define bioaccumulation.
2. After exiting the VLE, the participant will understand the two primary ways in which mercury ends up in the oceans/waterways.
3. After exiting the VLE, the participant will understand why large fish have the highest concentration of mercury in the food chain.
4. After exiting the VLE, the participant will determine if it is safe to eat seafood.

APPENDIX J

IRB APPROVAL LETTER

## EXEMPTION GRANTED

Brian Nelson  
 CIDSE: Computing, Informatics and Decision Systems Engineering, School of  
 480/965-0383  
 Brian.Nelson@asu.edu

Dear Brian Nelson:

On 10/22/2013 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	High Fidelity Virtual Environments: Do Shader Quality or Higher Polygon Count models increase Presence and Learning?
Investigator:	Brian Nelson
IRB ID:	STUDY00000073
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	<ul style="list-style-type: none"> <li>• Horton consent Document, Category: Consent Form;</li> <li>• HRP-503a - PROTOCOLSOCIAL BEHAVIORAL_Horton_Final_v3.docx, Category: IRB Protocol;</li> <li>• Attitudinal_survey_final.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);</li> <li>• Demographic information_final.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);</li> <li>• Mercury_test_questions_final.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);</li> <li>• Presence Vs4_reduced_final_v2.pdf, Category: Measures (Survey questions/Interview questions</li> </ul>

	/interview guides/focus group questions); • Horton_verbal-script_v1.pdf, Category: Recruitment Materials; • Research study flier_v2.pdf, Category: Recruitment Materials;
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The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 10/22/2013.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator cc:

Scott Horton  
Scott Horton