Water on Tap
The Use of Virtual Reality as an Educational Tool

by

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Abstract

Water on Tap
The Use of Virtual Reality as an Educational Tool

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A study was conducted that explored Virtual Reality (VR) as an educational tool. High school students created water molecules in an immersive virtual environment. They were tested on their knowledge of atomic and molecular structure before and after their VR experience. These results were compared to the test results of students who experienced other educational media in learning the same topic. The other media differed from VR in terms of immersion and interactivity.

Interactivity was found to be significant, while immersion was found to be insignificant. Issues of training, world design, assessment, hardware resolution, and student population were suggested as possible reasons for immersion's lack of significance in this study.

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Mom, Dad, Cheryl, Garey, Joe, Robin, Karen, Brooks, Steve, Marie, and all the kids provided a strong base for me and said a lot of rosaries. Rach’s family didn’t say rosaries for me, but they also provided support. (This acknowledgment obligates Ruth to mention me in her next book). Amy knew me when. Laura and Barbara created a space for me and my heart. Michelle and Bernie provided a mirror. Tess (the artist) and Subway sandwiches were a wonderful Wednesday afternoon ritual. OK, Subway sandwiches were more than just Wednesday afternoons. Tawnya and all the actors added balance to my life as well as putting me off-balance. Many more friends gave of themselves and although I will leave them as anonymous, I do not do so out of a lack of deep connection. Finally, my deepest gratitude goes to Rachel and Blue. You know.

To: Raven, Rowan, Fairy, & Flax

CHAPTER 1: Introduction

Purpose of Dissertation

In this dissertation, I wished to investigate the use of VR as an educational tool. This study is not intended to be the final word on VR and education. Rather, this dissertation is considered to be an early step in systematically exploring how VR can contribute to the field of education. The hypothesis of this dissertation is that VR is extremely useful for at least one particular topic of education since VR has a high degree of interactivity and immersion. The educational topic chosen to explore this hypothesis was atomic and molecular structure at the high school level. If this proves to be true, other studies will have to extend the hypothesis to include other topics. Questions included whether VR actually is useful in helping students improve their knowledge of chemistry and if so, whether VR's interactivity and immersion were the reasons for this improvement. These questions formed the basis for the experimentation. In the assessment section of this dissertation, I will define the metrics used to quantify the answers.

Different media were studied for comparison and will be fully explained in the experimental set-up section. The main difference among the treatments were the varying degrees of interactivity and immersion. The VR treatment consisted of high interactivity and immersion. The Mac Interactive treatment also consisted of high interactivity, but no immersion. The Video treatment and the Mac Run treatment were both treatments of no interactivity and no immersion. Figure 1 shows a graph of the relationship between the media treatments. There were two reasons why there was no treatment of high immersion and low interactivity. The first is that while interactivity is not inherently tied to immersion, immersion is closely tied to interactivity. In an immersed environment such as VR, if you move your head to change your perspective, you are interacting with the environment. So, it is problematic and artificial to eliminate all interactivity from an immersive treatment. I could have had the students look only in one direction in the virtual world while I operated the controls. However, this detracts from the feeling of immersion. Furthermore, this scenario leads to the second reason. Too many people would get sick in this scenario. From past experience of demonstrating many virtual worlds, I found that people need to be in control of their own movements while in a virtual world or they tend to become queasy. Since I was working with high school students who had volunteered for this experiment, I did not feel it was appropriate to expose them to a high probability of motion sickness. However, a great deal of information can still be gained in this experiment even without the high immersion, low interactivity treatment.

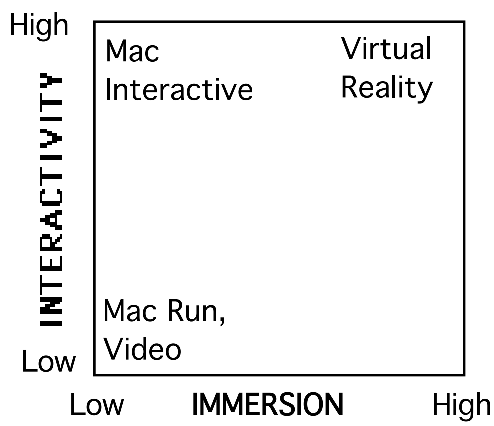


Figure 1: Immersion/Interactivity Chart

Definition of Virtual Reality (VR)

“Virtual Reality” (VR) is strictly defined in this dissertation as a specific technology. This technology is computer based and gives the illusion of being immersed in a 3-dimensional space with the ability to interact with this 3D space. The interface hardware components consist of a visual display apparatus, some sort of input device, and a position sensor. Typically, the visual display that is used is a helmet that places a television-like screen over each eye, blocking one's view of the physical world. Instead, of the physical world, one sees a 3-dimensional rendition of a place that is created by computer graphics. The 3D effect is obtained by taking advantage of depth clues such as occlusion and the correlation between distance and size. For stereographics presentations, the view from each eye is slightly different in order to utilize the depth perception capability of two eyes.

Input devices can range from a keyboard to a mouse to a wand to a fiber optic glove. The purpose of the input device is to allow the human participant to give electrical signals to the computer which can be interpreted as specific commands. Depending on how the software was programmed, one mouse button or hand gesture might represent "fly forward" while another button or gesture means "fly backward."

The position sensor in VR keeps track of the absolute physical position of the participant and gives that information to the computer. Usually, a position sensor is placed on the participant's helmet as well as on the input device. With the helmet tracker, the computer is programmed to know that the front of the tracker matches the direction in which the participant is looking, and then generates graphics to correspond to that direction. The input device tracker allows the computer to calibrate the position of the participant's hand. Therefore, the computer can generate a "virtual hand" that corresponds with the participant's real hand. That virtual hand can then grab virtual objects and move them around as the participant moves in the physical world.

The position tracker is a key technology in enabling the illusion of immersion. As participants turn around in the virtual world, the visual image changes. For example, in Virtual Seattle, they would see the skyline of the Seattle buildings in one direction. As they turned around, they would see the Olympic Mountain range behind them, giving them the feeling of being surrounded by the Puget Sound area. This is the illusion of immersion.

Previous Studies

The computer technology of Virtual Reality (VR) offers educators a new way to teach effectively. At the Human Interface Technology Lab (HITLab), a part of the Washington Technology Center at the University of Washington in Seattle, several pilot studies had been performed to examine VR's potential in the field of education including, "Pacific Science Center 1991," "Pacific Science Center 1992," and "HIV/AIDS." While these studies were not comprehensive, they did offer guidance in our continuing examination of VR and education.

Most of the research in education at the HITLab involved having groups of students create their own virtual worlds by using 3D drawing software on a Macintosh computer. Researchers at the HITLab programmed the students' worlds into fully immersive virtual worlds that the students could "visit" by donning headgear and a glove at the HITLab. The Pacific Science Center studies used 10 to 15 year old students who were attending a week-long summer day camp. Some of these students had extensive computer knowledge, while others were novice computer users. As part of their camp, they learned about VR. In groups of 10 or so students, they brainstormed virtual world creations. In sub-groups of 2 to 3 students, they created objects for their world along with specifications as to how the objects should be placed and move in the virtual world.

While we enjoyed watching the children create their world, the most exciting part of the process for us as researchers was to see all of the students experiencing VR. Everyone said that they wanted to come back and try VR again. They all talked about how much fun it was. Clearly, VR was a motivating force for all the children. We had expected to see that students who loved computers would also love the next step in computer technology, but we had not been sure of what to expect from students who had expressed little interest in technology. We had a few theories as to why the children might enjoy VR. The most obvious reasons were that VR is new and different and it enables people to do things that they cannot do in the physical world, such as fly and go to places that do not exist. Furthermore, for people who get to build their own world, the creation process is a big draw. These reasons were substantiated by the students' answers when we asked them what they liked best about VR ("I liked being in control of my actions and experiencing the result of our designing for the world" "flying" "It was cool to be able to make a world and actually go in it.").

A deeper, more transparent reason may exist as to why the children, including those not typically engaged by computers, enjoyed VR. We theorized that due to the less symbolic requirement of VR, the frustration level with using this technology was reduced, thereby allowing the fun of the program through. Since symbols are highly related to the culture in which they are derived, people outside of that culture are at a disadvantage. In the VR world that the kids created, there were no esoteric metaphors to get in the way, and no highly coded commands to know. If people wanted to look behind them in VR, they merely turned around in the same way as they would in the physical world. Everyone has experience in the physical world and they can build on that knowledge in the VR world. The hurdle of "feeling stupid" is reduced.

From the experience of the summer camps, we had evidence that VR has a definite role to play in education, if merely from a motivational viewpoint. However, this should not be extrapolated to the idea that VR should be used for every aspect of education. While VR may offer something for every subject, the cost of the system, especially at current prices means VR is a heavy resource sink. VR should not be artificially forced into a subject when another method is available that teaches roughly as well for a lot less money. Not only is this a bad decision from an economic standpoint, but it also a bad decision for VR. The message is sent that there are not enough real ways that VR can help education, so fake situations are fabricated. For example, a world in VR could convey a foreign country for a social studies class. However, a film can convey much of the same information with better resolution for a dramatically lower cost. To use VR in this case, is to not acknowledge the power of VR.

There are many subjects that VR can fill a void that cannot be currently covered. For example, subjects that rely heavily on visualization of abstract concepts are a prime topic for VR use. While the social studies example does rely on visualization, the country is a real place that can be captured visually by relatively cheap equipment. A subject such as chemistry or physics requires visualization, but of a more abstract kind. What does an electron or atom really look like? A student may get to visit a foreign country and interact with other people, but will never get to interact with an electron on a human level. VR lets students "see" the subject who learn best that way instead of just reading or hearing about. That is a non-trivial use of VR in education. VR should not be used in superfluous ways at this time. If the resource drain of VR diminishes greatly in the future, then maybe an argument could be made for a more ubiquitous role for VR.

The other downside of VR is that not everyone likes it. A huge number of people do love it, but it is not unanimous. Of course, it is rather unrealistic to think that anything in the world would have full agreement and VR is no different. During the summer camp, we had almost 70 children go through VR and one girl just did not like it. We asked everyone to rank their feelings about going into VR again on a scale of 1 to 10, where 1 is not at all and 10 is the equivalent of "yes, yes, yes, please let me go back in." The overall mean was 9.35 with a mode and median of 10. This particular girl answered with a 1. The next lowest score after hers was a 5. Maybe she would grow to like VR if she had more exposure. When questioned, she stated that she was scared to go into VR and would rather just build worlds on a computer. She was not able to articulate what aspects of VR frightened her. Interestingly, other students cited safety as their reason for liking VR. They felt safer in VR than in their real lives. Whatever the viewpoint, individual differences need to be respected. For the one girl, at this time VR is not a good learning tool and to force her to use it may not be beneficial.

The HIV/AID study extended the student population that was observed. We chose to work with students who were not doing well in a traditional educational setting and typically would not be seen at a computer summer camp. This decision was based on our commitment to making VR as accessible and as useful as possible. We used the same structure that we used with the summer camps with the students creating the objects on a Macintosh and the researchers transforming the objects into a virtual world. The difference was that the students did not choose the topic. Rather, their teachers decided that they would create a world about HIV/AIDS.

Again, with this project, we found that the students enjoyed participating. The final piece of the project was the students' visit to the lab to see their world. Each student had one turn to spend about 5 minutes being inside VR by wearing the VR headgear and using a hand-held wand that controlled movement. Everyone else could see what was going on in the virtual world by watching a TV screen. On the day of the field trip, all 15 of the students showed up to school on time, which was quite unusual for this population of students. While most of the students enjoyed being in the world that they helped to create, we did see different initial reactions. The differences actually followed a pattern that we see at the lab with student groups, often dividing along gender lines. Some of the students were very enthusiastic and wanted to go first and win the game; these students were mostly boys. Other students, mainly girls, hung back and did not even want to try the technology. We felt that this shyness was due to the competitive group dynamics at play, rather than to a fear of VR. We let the enthusiastic ones have their turns first, and they had a great time both being in the virtual world and also coaching and commenting when others were in the virtual world. After a while, they became bored with watching and start wandering around the lab, looking at other things. At that point, we were able to coax the reticent students into at least trying on the headgear to see what viewing a virtual world would feel like. We assured them that they did not have to play the HIV/AIDS game, instead they could just fly and look around. Most of these students ended up playing the game once they were inside the world. Only one student (a boy) never tried VR at all.

Overall, we feel very positive about the project and the impact it had on the students. Although, we did not collect "hard data" with this project, we were able to gather information through anecdotal and personal observation. We felt that the "At Risk" students learned about AIDS and computers while they created their HIV/AIDS world. They showed up to class more often and with more enthusiasm, particularly around the time of the field trip. Some of the students lectured about this project at other school locations and have volunteered to become part of a citywide AIDS peer education program. We felt that they became more engaged in school.

This dissertation was the natural extension of these studies. While these studies offered hope for the potential of VR, there was still the need to explore this potential in a more structured manner.

Theory

Educational theory and cognitive science support the exploration of VR as an educational tool. In the field of educational theory, the concept of constructivism powerfully articulates an effective strategy for teaching children. Its proponents advocate that students should be fully involved in their education instead of playing the role of passive sponges waiting to be told the correct answers. The actual methods that constructivist teachers may use vary greatly. At one extreme, teachers may propose that there are no correct answers and that individual students must discover their own truths. Jonassen writes,

"constructivism, on the other hand, claims that reality is more in the mind of the knower, that the knower constructs a reality or at least interprets it based upon his/her experiences. Constructivism is concerned with how we construct knowledge from our experiences, mental structures, and beliefs that are used to interpret objects and events. Our personal world is created by the mind, so in the constructivist's view, no one world is any more real than any other. There is no single reality or any objective entity" (Jonassen, 1991, p. 29).

Other constructivists do not have such a fluid belief in truth. Although they also label themselves as constructivists since they want the students to come to terms with the information themselves, these teachers believe in right answers. An example of this teaching method is "The Adventures of Jasper Woodbury," a videodisk program for teaching math that was developed by The Cognition and Technology Group at Vanderbilt (CTGV). "Jasper" consists of 4 adventure stories designed to provide students with real-world, open-ended problems that do have correct mathematical solutions. CTGV believes "that the realistic nature of our Jasper problems (including their complexity) helps students construct important sets of ideas and beliefs and refrain from constructing misconceptions" (CTGV, 1991).

Using constructivist theory, I created the virtual chemistry world to encourage students to learn by exploring and interacting with the information. Instead of sitting in a classroom and passively viewing images of atomic orbitals, students can place electrons into a atom and see the atomic orbital appear as the electron buzzes around. Like the Jasper problems, there are correct answers in the virtual chemistry world. Electrons must be placed in the atom according to the laws of chemistry with the correct energy and spin, otherwise a belching sound is heard and the electron floats back to its starting position. If constructivists' interpretations are valid, the chemistry students should learn much more about the rules of atomic structure with this method, than if they just passively watched the atom being built.

Cognitive science is another field of knowledge that guided my use of VR as an educational tool. Since cognitive scientists study how the human mind works, their theories can address how VR can help students learn. According to cognitive theories, VR can help humans process information and therefore learn, by making abstract concepts more concrete. This transformation from abstract to concrete is important because of the way we think. According to many cognitive scientists (Newell, 1990; Johnson-Laird, 1988) humans think symbolically. Furthermore, some symbols are referring to concepts that are more concrete than others, such as the proper noun, "Seattle" versus the label "city A." Johnson-Laird has shown in his syllogism studies that we process concrete symbols better than abstract ones (Johnson-Laird, 1983). This may be due to the way that humans are hard-wired. We may excel at pattern recognition of concrete symbols such as a tiger in our visual field, because of the evolutionary advantage of being aware of tigers. VR can present abstract information in concrete forms that humans have been processing for eons by immersing people in a visual computer-generated world.

Atomic and Molecular Structure

To test the idea that VR is a good medium for making abstract concepts concrete, and therefore easier to learn, we needed a subject area to examine. The topic of atomic and molecular structure is an excellent example of an abstract topic that is difficult to learn. The difficulty of understanding scientific concepts is well researched (Garnett & Treagust, 1992; Ross & Munby). "Students' misunderstandings and misconceptions in school sciences at all levels constitute a major problem of concern to science educators, scientist-researchers, teachers, and, of course, students" (Zoller, 1990, pg. 1054). This difficulty is attributed to the abstractness of the scientific topic (Millar, 1991; Johnstone, 1991; Brown, 1992; Griffiths & Preston, 1992). Misconceptions can arise when students attempt to align what they know about the physical world from their experience of it and what they are taught in class. For example, students see ice melt into water and are taught in class that the velocity of the H_2O molecules is increasing during that process. However, the students are not able to use their powers of observation to understand this chemistry concept. In the same way, the students cannot directly experience atomic and molecular structure.

In the virtual chemistry world, students experience abstract concepts taking shape in concrete forms. For example, the students can "grab" an electron represented by a spinning minus sign. Theoretically, this enables them to build a concrete mental model about the abstract information that electrons have certain spin and energy components. Some people may object to this representation, since electrons do not really look like spinning minus signs. However, since electrons are not visible to humans, any way we describe them is a model. Furthermore, as Johnson-Laird points out, "small-scale models of reality need neither be wholly accurate nor correspond completely with what they model in order to be useful" (Johnson-Laird, 1983; pg. 3). VR can present models that highlight the information deemed appropriate by the instructor.

Theoretically, the power of VR is more than simply presenting visual symbols in order to create concrete metaphors. A key aspect of VR is that people are immersed in a virtual world of these concrete forms. These forms produce the participant's environment. A Macintosh computer can display minus signs representing electrons, but the viewers do not typically feel like they are on the same plane as the objects. A reasonable assertion to make is that information presented in an immersive 3D spatial manner is more concrete than information presented in other ways. We use more than just our visual sense in moving through the world. A tiger is not just a 2D image on our retina. It is a 3D object that relates to ourselves in terms of mass, distance, etc. We process information by how it relates to ourselves and being immersed in a 3D world gives us more opportunities to use that skill. Comparing VR to other media will allow me to explore the veracity of this assertion.

CHAPTER 2: Experimental Design

Pilot Study

A pilot study was conducted for the VR treatment to see if the students could use the virtual chemistry world, if certain aspects of the world were confusing and needed to be modified, and if the tests were at the proper level for the student population. Several changes were made due to the results of the pilot study and included in the main study.

Subject Population

Students volunteered to be a part of this study by returning a parent permission form in compliance with the human subject review panel (HSR 23-510-E). These students came from chemistry classes in which atomic and molecular structure had already been taught. The students took pre-treatment written and oral chemistry tests on atomic and molecular structure. They will be discussed in more detail below. They then participated in one of the treatments discussed in the following sections. Finally, they took post-treatment written and oral tests.

For the VR treatment, thirty-eight high school students, 25 females and 13 males, who were in their second semester of junior level high school chemistry class participated. They had been taught atomic and molecular structure in their first semester of class. They were all novice users of VR. Students were encouraged by their chemistry teacher to volunteer for the study and received class extra credit for their participation. The study was conducted at the HITLab after school hours. All but four of the students were taught chemistry by the same teacher. Data from two of the 38 subjects were removed from the study because of failure to follow instructions.

The Video treatment consisted of twenty high school students, 10 females and 10 males, who were in their second semester of junior level high school chemistry class. They were from the same student population as the VR treatment. The study was conducted at the school during school hours. All of the students were taught chemistry by the same teacher.

The students for the Mac Interactive treatment were drawn from a similar, but different population than for the VR and video treatments and consisted of 14 students, 7 females and 7 males. The VR and Video treatments had exhausted the supply of possible participants and so a different high school was used. The students for this study had taken chemistry class the previous year from one of two teachers. Although these students had finished their chemistry course at least 4 months before and the VR and video students had still been in chemistry class at the time of their participation, the topic of atomic and molecular structure was taught early in the first semester for both groups. Therefore, an assumption of this study is that the subject was taught long enough ago for both groups that the groups consist of similar populations. A comparison of the pre-test scores found no significant difference between these students and the original student population used for the VR and Video treatments.

The Mac Run students were drawn from the same population as the Mac Interactive group There were 14 students, 5 females and 9 males.

The control group had 7 students, 5 females and 2 males drawn from the same population as the VR and video treatments.

The student population for the long term retention study was a subset of the students who participated in the VR, video, or control treatments. 18 students from the VR treatment, 17 students from the video treatment and 5 students from the control group participated.

VR Treatment (High Immersion / High Interactivity)

Apparatus

A drawing of the physical set-up is shown in Figure 2. The helmet was the “VPL EyePhones” which has a resolution of 86,000 pixels and a field of view of 100 degrees. The helmet was connected to the ceiling with rope and a pulley system so as not to put any weight on the participant’s head. The wires connecting the helmet to the computer were also attached through the pulley system.

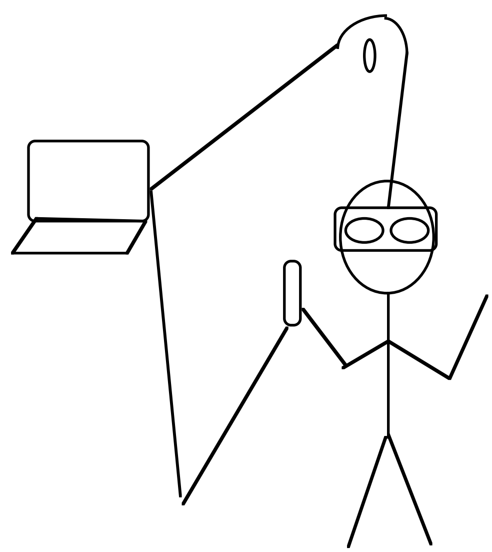


Figure 2: VR Apparatus

The wand was a modified “joystick” for a standard video game. It was a hand-held device, as opposed to being attached to a base or table and it had three buttons and one trigger (see Figure 3). In software, the left button was programmed as “fly forward”, the right button meant “fly backward”, the trigger represented “grab object” and the middle button was programmed as “let go of object.” Wires connecting the wand to the computer ran from the bottom of the wand and across the floor. The participants had to be careful to not trip on the wires as they turned around.

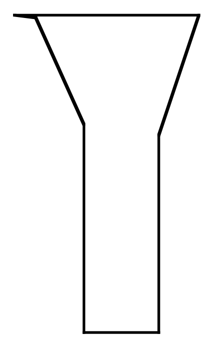


Figure 3: Wand

Polhemus position sensors were used for the position sensors in this experiment. Polhemus sensors are electro-magnetic sensors and require an emitting device and a receiving device. The emitting devices were placed on top of the helmet and inside of the wand and the receiving devices were placed next to the computer.

The computer was a Silicon Graphics Iris 320VGX. The software that ran the virtual world was Virtual Environment Operating System (VEOS) created by members of the HITLab (see Coco, 1993). The virtual chemistry world application was written in LISP using digital studio, a VEOS interface program written by Colin Bricken.

Procedure

Students who participated in the VR treatment of the experiment were first told about the technology of VR. I explained that the graphical images that were displayed inside of the helmet were generated by the computer and would change as they moved their orientation and position. I then demonstrated the virtual chemistry world by creating a lithium atom and then bonding it to a hydrogen atom in the virtual world. The step by step process illustrated both the VR system as well as the rules of atomic structure that they had learned in chemistry class.

After the demonstration, each student put on the helmet, held the wand and built a virtual atomic structure. They were given the task of building a virtual water molecule, which was done by creating a virtual oxygen atom and then combining it with two hydrogen atoms. Figure 4 shows what the students would see in the virtual chemistry. The “plus” shape represented the proton, the “minus” shape represented the electron, and the sphere (a “zero” like object) represented the neutron. These were always available. For example, when one proton was grabbed, another proton appeared in its place. Since the students were taught that an electron has a spin and energy associated with it, a spin indicator represented by a triangle and an energy gauge represented by a bar also appeared in the world. A large wireframe cube was the “atom building area” where the students placed the atomic particles. A shape representing hydrogen and a box representing a “quick fill” function were also present. I will explain those two items in context of the procedure that the students used to build the water molecule.

Students began by grabbing a proton and placing it in the atom building area. They did this by moving their hand around until they saw their virtual hand intersecting the virtual proton. They then pushed the “grab” button on the wand and the virtual proton would stick to their virtual hand. They then moved their hand until the virtual proton intersected with the atom building area. They might have had to use the fly forward or backward buttons to reach the atom building area. They could then push another button to release the virtual proton from their virtual hand. This maneuvering took some practice.

Figure 4: Virtual Chemistry World

After the proton was placed, the students had to grab an electron. The electron object spun in a clockwise manner to indicate its spin status. The energy bar began at its default energy level of 1s. Therefore, the student did not have to adjust anything. When the first electron was placed, the 1s orbital would appear, represented by a wireframe sphere (see Figure 5). The electron would buzz around inside the sphere 90% of the time, appearing and disappearing randomly. The other 10% of the time, the electron would appear outside of the orbital object. This represented the chemistry concept that orbitals are merely probability areas where the electron can be found a certain percentage of the time. The 1s orbital appeared as a wireframe object because it was half full.

Before the student could place a second electron, its spin had to be changed. This was done by placing the virtual hand over the spin indicator and clicking the grab button. The spin indicator operated as a toggle switch, so clicking on this button changed the spin to whatever it had not been before. The student then grabbed the electron and placed it in the atom building area. When the second electron was placed in the atom building area, the 1s orbital turned solid to indicate that the orbital was full (see Figure 6). Inside of this orbital, the two electron continued to buzz around 90% of the time. If the student forgot to change the electron spin, the electron could still be placed inside of the

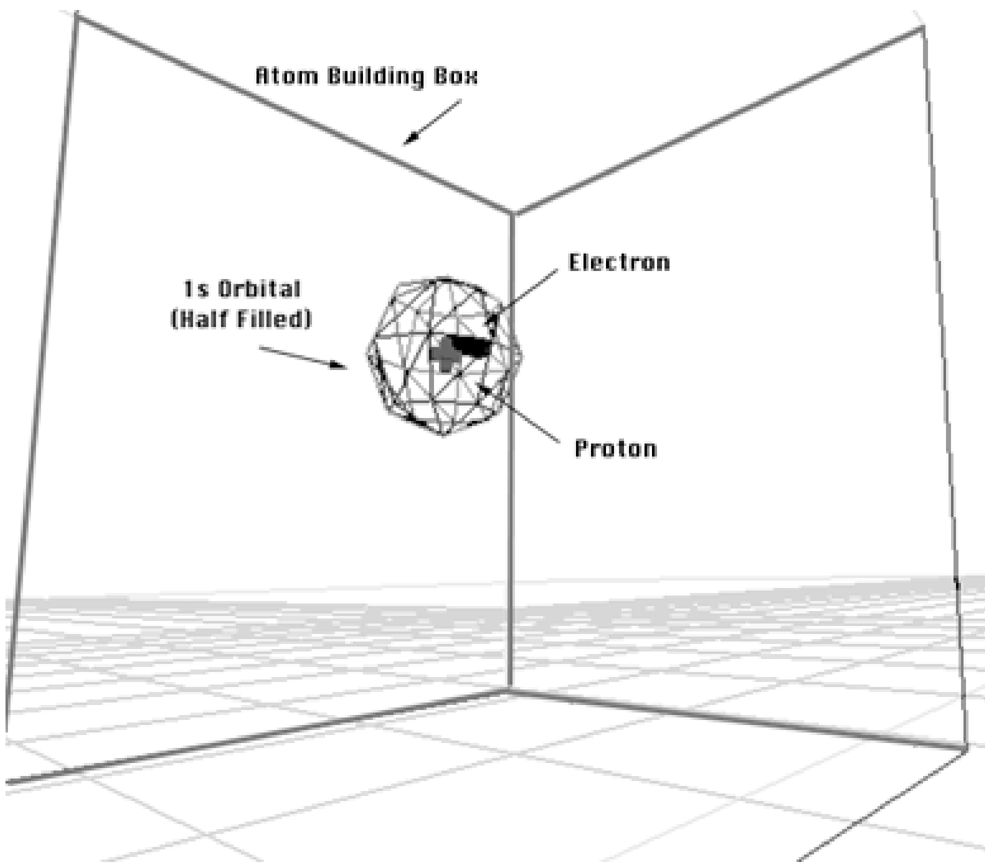


Figure 5: 1s Orbital

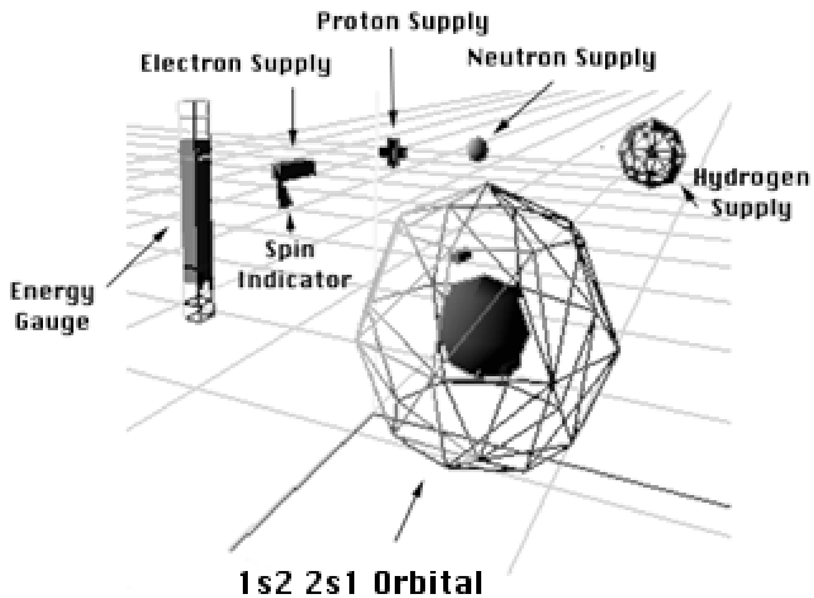


Figure 6: 1s2 2s1 Orbital

atom building area. However, instead of seeing the electron buzzing inside the solid orbital, the orbital would remain as a wireframe object, the electron would float back to its starting position, and a belching sound would be heard. This was counted as a spin error. If students attempted to place the same electron again without correcting for spin, I interrupted them and explained the error.

To place the third electron, the energy had to be increased to the 2s level. Students did this by repeatedly clicking on the energy gauge (shown in Figure 7). The gauge was similar to a thermometer and the "mercury" in the gauge would increase as the student clicked the icon. When the gauge was at the 2s level, the student could then grab the electron and place it in the atom building area. The 2s orbital then appeared, represented by a wireframe sphere that surrounded the solid 1s orbital (see Figure 7). Again, the electron would buzz around inside this area. If a student did not increase the energy to the correct level, when the electron was placed it would float back to its starting position with a belching sound. This was counted as an energy error.

Students did not have to keep the atom balanced by placing protons and neutrons as they went along (see Figures 8 to 10). I made this decision because the procedure for doing so would have been too tedious. Instead, after the students finished placing the

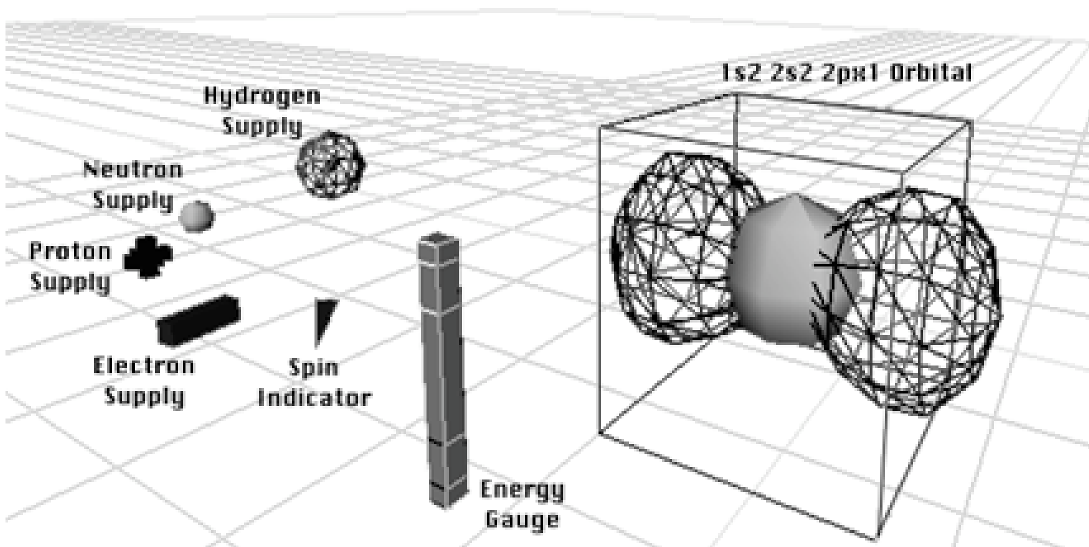


Figure 7: 1s2 2s2 2px1 Orbital

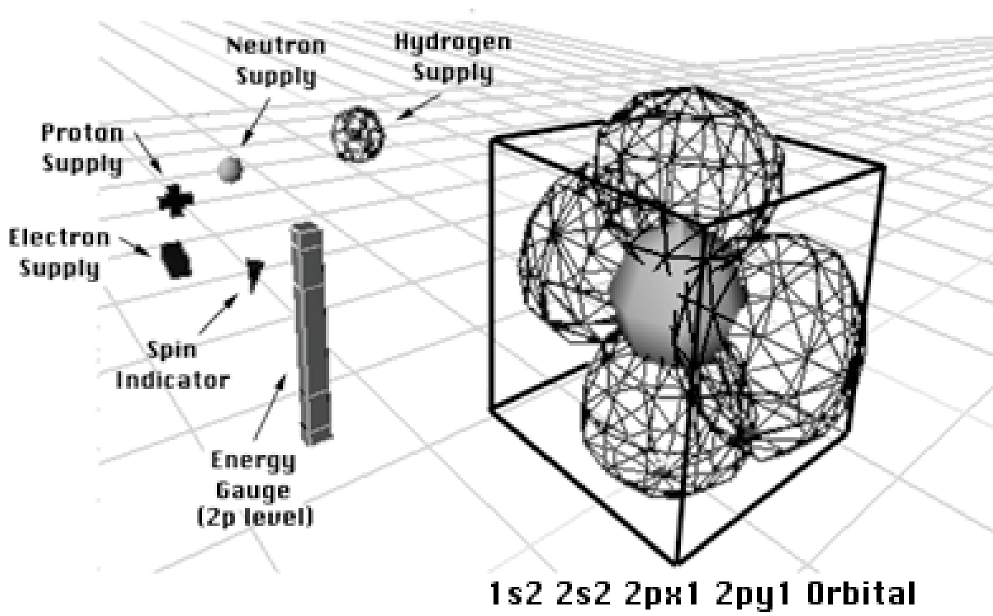
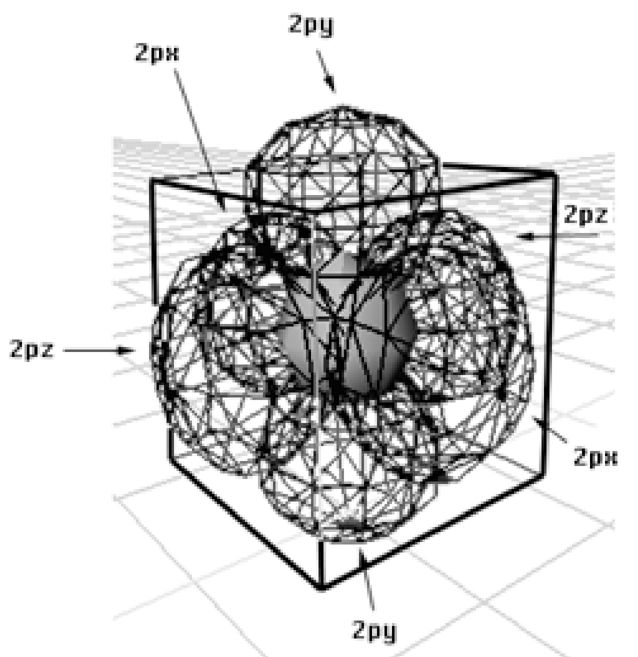


Figure 8: 1s2 2s2 2px1 2py1 Orbital



Fig

ure 9: 1s2 2s2 2px1 2py1 2pz1 Orbital

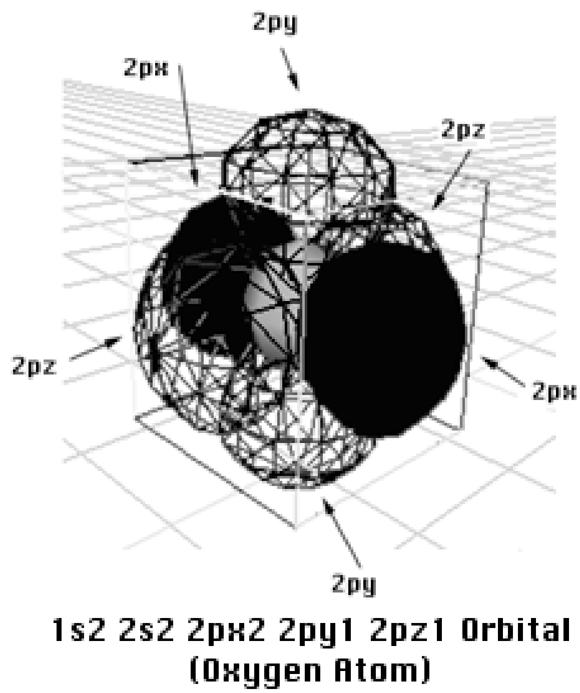


Figure 10: 1s2 2s2 2px2 2py1 2pz1 Orbital

correct number of electrons for an oxygen atom, they clicked on a “quick fill” box and the correct number of protons and neutrons floated into the atom.

To help the atom building process, sound effects were included for feedback. Sounds existed for the completion of any sub-task such as grabbing a proton, placing a proton, changing the electron spin, or as previously mentioned, whenever an error was made. The students had to place eight electrons and “quick fill” the rest of the protons and neutrons to complete the oxygen atom. When the atom was complete, the students had to bond it with two hydrogen atoms. The object representing the hydrogen atom consisted of an electron buzzing around inside of a wireframe 1s orbital with a proton in the center. The students would grab the hydrogen atom and place it so it was touching one of the half filled orbitals of the oxygen atom (see Figure 11). When bonding occurred, the oxygen orbital and the hydrogen orbital would both turn solid to indicate that they should be considered to be full orbitals. Additionally, a laughing sound was heard to indicate that the orbitals “preferred” to be in that state. The students placed two hydrogen atoms to illustrate a stable water molecule with no available orbitals (see Figure 12).

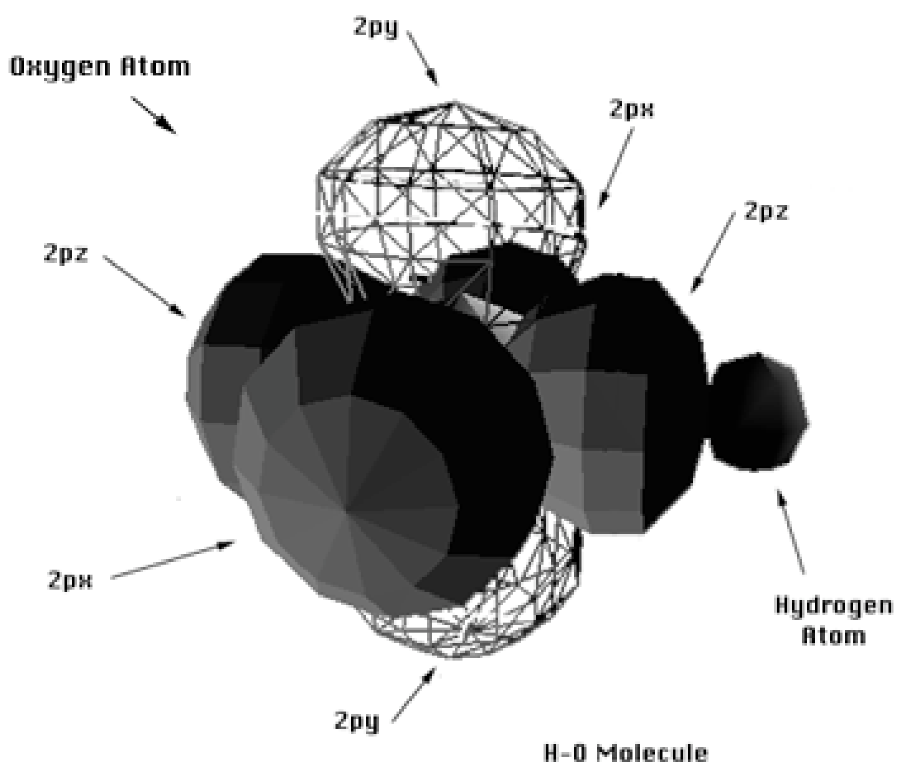


Figure 11: H-O Molecule

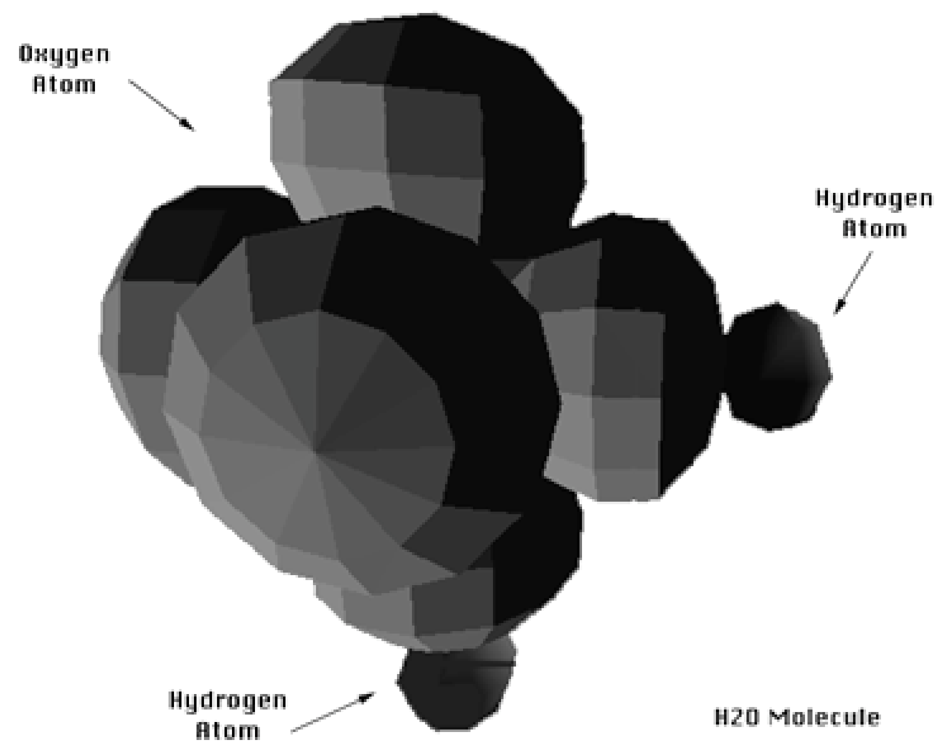


Figure 12: H_2O Molecule

Video (Low Immersion / Low Interactivity)

Apparatus

The purpose of this treatment was to mimic the VR treatment, but without the immersion or interactivity aspects. A video tape was created by recording what was seen on the left eye display as I created virtual atoms within VR. While I built the atom, I also taped my voice narrating what was happening. For the tape, I built a lithium atom to imitate the VR demo I gave to the VR treatment students and then I built a water molecule to impersonate what the students did while in the virtual environment. I did not mimic any of the typical mistakes that the VR students made, such as not changing the spin or energy level. Full computer sound was included as well as my voice narrating the building process. This video tape was played on a VCR connected to a 19 inch television placed 6 feet away from the participant.

Procedure

The video tape was played while the student watched silently. This situation allowed the student to view and hear the same symbolism that the VR participants experienced, but on a flat 2D television screen and without any chance of interactivity.

Mac Interactive (Low Immersion / High Interactivity)

Apparatus

The purpose of this treatment was to mimic the VR treatment without the immersion element, while maintaining the interactivity aspect. I programmed a chemistry world to run on a Macintosh computer with a standard 2D display. Using MacroMedia's Authorware and Director software, I created the same virtual atomic objects for the Macintosh that I had programmed for the VR system. Students could grab the protons, electrons, and neutrons and drag them into the atom building area using a standard mouse input device. The spin indicator, energy level, "quick fill" box, and hydrogen atoms were all present and had the same functions as in the VR version. The Mac objects had a different look than the VR objects due to the lack of depth. Figure 13 shows the Mac view. There was no immersion effect with all of the objects in view at one time on the Mac.

A Macintosh Quadra with 8 MB of RAM, 40 MB of hard drive, and a 13 inch color screen was used for this treatment. The students sat one foot away from the screen while interacting with the program.

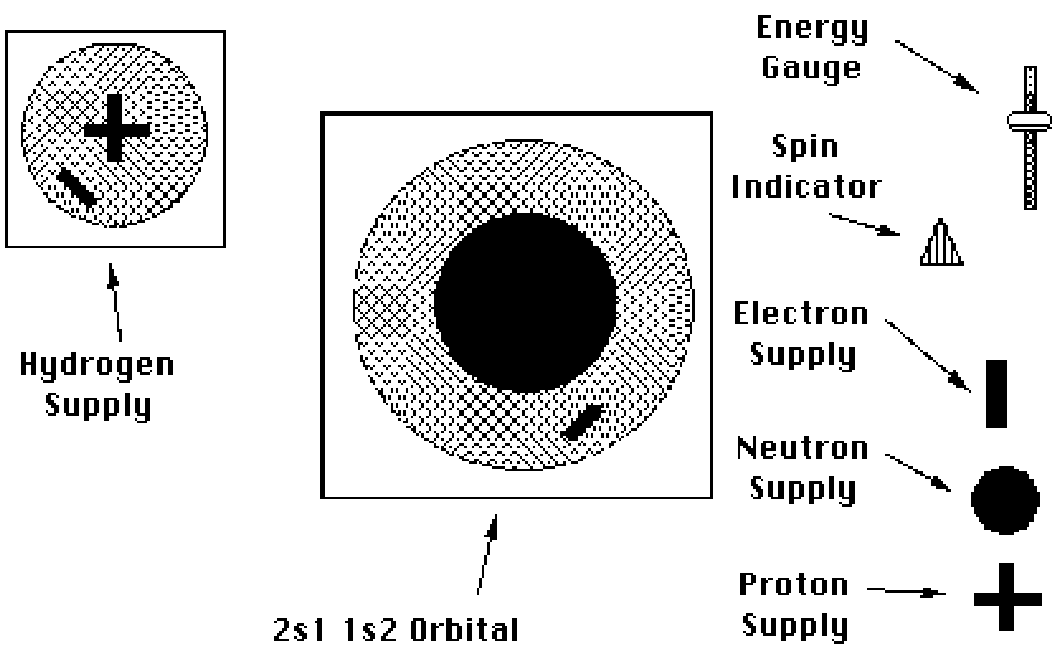


Figure 13: Macintosh Chemistry World

Procedure

I demonstrated the Mac chemistry world by creating a lithium atom on the screen and then bonding it with a hydrogen atom. I explained the functionality of the system including the spin and energy indicators. All of the students had used a Macintosh before, so I did not need to explain how to use the mouse to click and drag objects. After the demonstration, the students created a water molecule on the screen.

<u>Mac Run (Low Immersion / Low Interactivity)</u>

Apparatus

The purpose of this treatment was to mimic the Mac Interactive treatment without the interactivity. In effect, this duplicates the no immersion and no interactivity state of the Video treatment. If interaction and immersion are the only significant factors, then the Mac Run results should be the same as the Video results. Changing the media can unfortunately result in changing more than the factors of interest, which in this case are immersion and interactivity. If the results of the Video and Mac Run treatments were not equal, then differences other than immersion and interactivity were involved. The reason this is important is that any unknown factors might also impact a fair comparison between the VR treatment and the Mac Interactive treatment.

I reprogrammed the Authorware software of the Mac Interactive to run through the building of a water molecule without a participant interacting with the computer. I narrated the water building process on an audio tape which I synchronized to the computer program. Again, a Macintosh Quadra with 8 MB of RAM, 40 MB of hard drive, and a 13 inch color screen was used for this treatment. The students sat one foot away from the screen while watching the program.

Procedure

I demonstrated the process of building atoms and molecules in the same manner as I did for the Mac Interactive treatment. Afterwards, the students watched the computer as the water molecule was built on the screen. They also listened to the synchronized audio tape explain what was happening on the computer. As with the video treatment, there was no interactivity because I controlled the computer program.

Control

The control treatment consisted of no multimedia presentation of atomic and molecular structure. The students were given the pre tests and then after a period of time, were given the post tests.

Other Experimental Factors

In addition to the main factors of immersion and interactivity, there were other factors worth exploring in the experiment. The prime one was student learning style, which has had a great deal of focus in the field of education. Howard Gardner in his book, Frames of Mind (Gardner, 1985) asserts that they are various natural styles of learning including linguistic, spatial, and logical-mathematical types. Different proponents of this theory have different ways of categorizing learning styles, but they all state that students will learn more easily if the style of instruction matches their style of learning. For example, a visual learner will do better if the instruction includes lots of pictures as opposed to all text. Unfortunately, there have been no conclusive studies proving that learning style is an important factor in education. In fact, many studies conclude that learning style is not an important factor.

Despite this lack of evidence, learning style is an interesting factor in studying VR, particularly the style of spatial learning. Spatial learners are characterized as people who can readily visualize and manipulate 3D forms in their mind. For example, the inventor Nikola Tesla claimed to be able to “project before his eyes a picture complete in every detail, of every part of the machine.” (Gardner, 1985, pg. 187). Since chemistry is inherently composed of 3D particles, the ability to visualize and mentally manipulate these shapes is extremely helpful. A famous example is the chemist Friedrich Kekule’s discovery of the structure of the benzene ring by dreaming of a snake eating its tail.

VR should exacerbate the difference between students who are identified as spatial learners and those who are not, since VR provides a 3D spatial environment for learning. For the instructional topic of atomic and molecular structure, this difference could be one of two opposite results. The first possibility is that VR will help spatial learners more since the material is being presented in a natural way for them. The other alternative is that the non-spatial learner will be helped more by VR. The problem for non-spatial learners in understanding spatial concepts might be due to a problem in creating a spatial mental model of the topic, not in manipulating the spatial mental model. If that is indeed the problem, then VR can present a spatial model for the student to use. If the problem is truly one of manipulating the mental model, then VR will not be very helpful.

To ascertain the students’ spatial ability, they were given the spatial ability portion of the Differential Aptitude Test (DAT) battery designed by Psychology, Inc. The reason that this test was chosen was its relevance to spatial problem solving and its long history of use. Unfortunately due to experimental constraints, the DAT was only administered to the VR, Video, and control groups. The VR and Video treatments do offer the extreme differences in terms of spatial environment, so conclusions will still be able to be drawn with this limited testing structure. The test was given during the students' regular chemistry class, one week before the experimental treatments began. The 2 dimensional, paper test consisted of a series of 35 unfolded boxes of various shapes and shading with a multiple choice of folded boxes. With a time limit of 15 minutes, the students had to choose which one folded box corresponded to the unfolded box.

Assessments

Pre-treatment and post-treatment chemistry tests were given to the students to gauge their acquisition of chemistry knowledge as a result of the treatments. This also allowed comparison among the various treatments. The challenge in creating these tests was to develop a metric that truly measured understanding of the subject instead of merely examining a student's ability to memorize the topic. Chemistry, along with many other topics, has two levels of knowledge associated with it. Chemistry happens to an excellent case study of a subject in which ability to follow the rules and understanding the rules can easily be confused. An example of the ability to memorize and follow the rules of chemistry, is being able to write that H_2O is the formula for water, which is a molecule with no free valence electrons. Understanding what the rules mean and how they relate to each other is shown if the student cannot only complete the orbital fill diagram for H_2O, but also understands the significance of that molecule having no free valence electrons.

After reviewing assessment options in the literature, I decided to use two tests, one written and one oral, for both the pre-treatment and post-treatment exams. Using two tests allowed me to acknowledge the range of assessment techniques and hopefully combine the strengths of the methods. These tools included: free flowing oral interviews, two-tiered multiple choice tests, "fill in the blank" tests, and multiple choice tests. The proponents of the oral interviews feel that asking open questions and having the students sketch some of the answers allows the interviewer to assess the students' deeper level of knowledge about the subject (Griffiths and Preston, 1992). They quantified their data by assessing the students according to a set of concepts. For example, they would ask questions about sizes of molecules so they could determine whether or not the student understood the concept of size.

The two-tiered multiple choice tests attempt to exploit the objectivity and ease of grading of the traditional multiple choice test with more information. So, a multiple choice question is asked about a certain topic and then a second multiple question is asked to elicit their reasoning in answering the first question (Treagust, 1988). The "fill in the blank" and multiple choice tests are commonly used in traditional textbooks and classrooms and need no elaborate explanation.

I chose to use the oral interview test and a written "fill in the blank" test. I agreed with the researchers who believe that the interview method gives the most complete information about the students' knowledge. However, in the context of a traditional high school chemistry curriculum there is a need to be able to relate the results here to the traditional method of assessment. Using both tests also allow me to compare the two methods and draw conclusions.

The written test was based on the textbook Chemistry (Herron et. al., 1993) and conversations with the students' teachers. The pre and post written tests had the same types of questions on them, but asked about different atoms and molecules. The pre test is shown in Appendix A and the post test is shown in Appendix B. The oral test, shown in Appendix C, was the same for both the pre and post test. The oral test was graded by an interviewer who did not know what treatment the participant experienced. The interviewer had a pre-med college background and was trained in the interview method during the pilot study. I graded the written test without knowing whose test I was grading. A numerical score was given for both the oral and written test. The grading of the oral test followed the method as outlined by Griffiths and Preston (1992). This method consisted of breaking down large concepts into very specific smaller concepts. For example, the concept "understanding a water molecule" was broken into smaller pieces such as "understanding that two electrons in the same orbital have different spins" and "a 2s orbital has higher energy than a 1s orbital." Throughout the test, the interviewer decided what smaller concepts the student had grasped. Each small concept was worth one point and the points were added for the final score.

Long term retention of knowledge was also assessed. For this experiment, I chose to test a sample of students 3 months after their participation in a treatment. Again, the oral test was the same, while the written test was altered slightly. Unfortunately, I was not able to include students from the Mac Interactive and Mac Run treatments in the long term retention testing. This was because these treatments were conducted at the end of the study.

CHAPTER 3: Analysis

Means and Variances

Tables 1 and 2 show the means of the test scores for the various media. Figures 14 and 15 show a summary of all of the media treatments. In these figures, the box on the left represents the pre test score and the box on the right represents the post test score for each treatment. These box plots graph the median levels and the range of the data points. The horizontal line inside of the box represents the median, where half the data points are above and below that value. The box edges represent the quartile median lines. For the upper box edge, one quarter of the data points are above that value and three quarters are below that value. The lower box edge is figured similarly. The whiskers represent the range of the data, unless there are outliers. If there are outliers, the whiskers represent the range of the non-outlier data. Outliers are defined as data points that are more than the length of the whole box outside of one edge of the box.

Table 1: Oral Test Means and Variances

Medium	Number of People	Oral Pre Mean	Oral Pre Variance	Oral Post Mean	Oral Post Variance	Oral Extended Mean
VR	36	3.306	7.990	6.583	13.164	4.333
Mac Int	13	2.071	3.833	6.231	8.192	
Mac Run	13	4.462	5.269	6.786	4.603	
Video	20	3.100	14.200	5.350	24.239	3.824
Control	7	4.429	9.952	5.143	8.476	5.500

Table 2: Written Test Means and Variances

Medium	Number of People	Written Pre Mean	Written Pre Variance	Written Post Mean	Written Post Variance	Written Extended Mean
VR	36	6.528	13.313	7.722	18.463	7.028
Mac Int	13	4.885	8.340	7.385	5.590	
Mac Run	13	5.730	11.410	7.692	11.561	
Video	14	6.572	8.981	6.893	10.276	7.618
Control	7	7.785	10.988	7.214	14.155	7.750

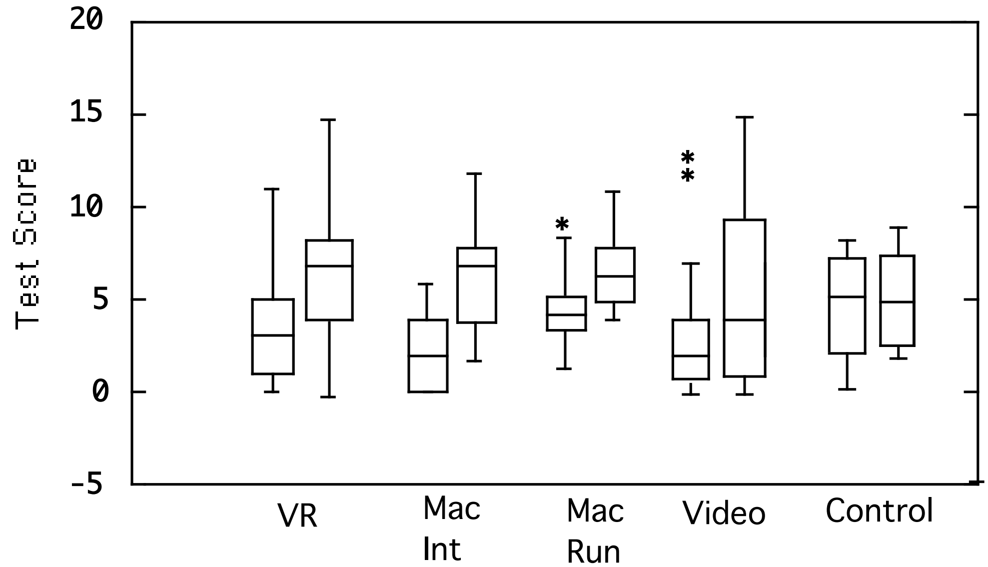
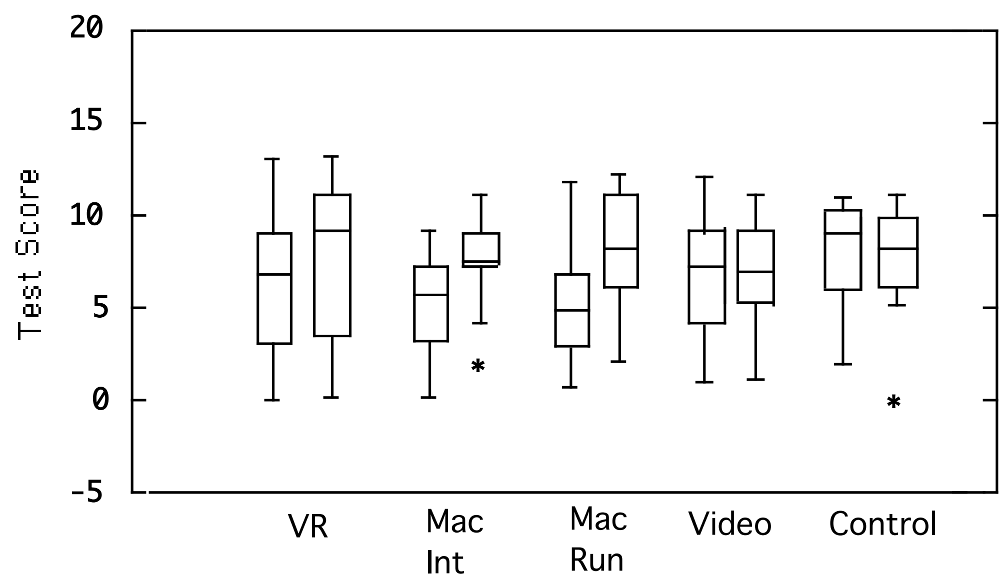


Figure 14: Oral Pre and Post Scores



Fig

ure 15: Written Pre and Post Scores

Assumptions

Independence

The independency of the media variable is the important assumption. To examine possible colinearity, a Pearson correlation analysis was run. Table 3 shows the Pearson correlation among the independent variables on a scale from -1 to +1 where a large number implies a large correlation. The values in Table 4 show the probabilities that the correlations are not significant, where a small number implies higher significant correlation. At an alpha of 0.05, Media is not correlated with any of the other independent variables, but all of the rest are significantly correlated.

The lack of independency among the oral, written, and DAT tests is an expected result and does not pose a problem. These three factors cannot be used as separate variables in the same analysis, but they were not intended to be used in that manner. The oral scores and written scores can be analyzed separately or combined into one factor. The DAT score can be used to predict the delta increase on the oral or written test, which eliminates the correlated pre test scores. The important assumption of the independency of the media variable was successfully met.

Table 3: Independent Variable Correlations

	MEDIA	Oral Pre Test	Written Pre Test	DAT
MEDIA	1.000			
Oral Pre Test	0.056	1.000		
Written Pre Test	0.072	0.570	1.000	
DAT	-0.121	0.493	0.469	1.000

Table 4: Independent Variable Correlation Probabilities

	MEDIA	Oral Pre Test	Written Pre Test	DAT
MEDIA	0.000			
Oral Pre Test	0.680	0.000		
Written Pre Test	0.593	0.001	0.000	
DAT	0.370	0.001	0.001	0.000

Normality and Variance

Another assumption is that the data is normal with equal variances. Referring to Figure 14, the variance and normality for the oral pre test look problematic. Variance is particularly important in experimental designs which have unequal cell sizes. To test the seriousness of the problem for the oral pre test, a Bartlett's test for unequal variances was run with a resulting chi-distribution statistic of 7.71 with 4 degrees of freedom. This value is significant at an alpha of 0.10, which means that the variances are significantly different at that level. Although an alpha of .05 is a typical cut-off value for significance, this significance is close enough to not be ignored and therefore, the assumption of equal variances for the oral test was not met.

For the written pre test shown in Figure 15, the data looks fairly normal. The Bartlett test statistic is 1.62 and is not significantly different at an alpha of .10.

Numerical Analysis

Table 5 shows the result for the media main effect using the Kruskal-Wallis method. Tables 6 and 7 shows the effect using the ANOVA method. The delta score which is the post score minus the pre score was used as the dependent variable. According to both the Kruskal-Wallis and ANOVA methods, media is a significant variable at an alpha of .05. Which medium is better can now be asked.

Table 5: Oral and Written K-W Delta/Media

Dependent Variable	Ind Variable	Number of Levels	N	K-W Test Statistic	Prob
Oral Delta	Media	5	89	15.842	0.003
Written Delta	Media	5	83	10.515	0.033

Table 6: Oral Test ANOVA Delta/Media

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MEDIA	79.651	4	19.913	3.354	0.013
ERROR	498.708	84	5.937		

Table 7: Written Test ANOVA Delta/Media

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MEDIA	62.239	4	15.560	3.024	0.023
ERROR	401.388	78	5.146		

To determine how the media were significant, a series of comparisons were made. The non-parametric analysis of Kruskal-Wallis was used again, but in a slightly different manner than before. Instead of examining all of the media treatments in one Kruskal-Wallis analysis, two groups at a time were analyzed. This method is appropriate, because the overall difference among groups was already determined to be significant. As before, while only the non-parametric analysis is necessary, the t-tests were also run to give a sense of the impact that non-normality and unequal variances had on the results. Table 8 shows the results for the oral delta test variable. The media are in order of largest oral delta score to lowest instead of being in order from most immersive/interactive to least.

Table 8: Oral Delta Test Comparisons

Media	Mac-Int	VR	Video	Mac-Run	Control
Delta Score	4.231	3.278	2.250	2.000	0.714

Comparison	Oral t-test	T sig dif	Oral K-W	K-W sig dif
M-Int/VR	0.213	No Dif	0.169	No Dif
M-Int/Video	0.060	No Dif	0.022	Dif
M-Int/ Mac-Run	0.012	Dif	0.016	Dif
M-Int/Control	0.001	Dif	0.004	Dif
VR/ Video	0.239	No Dif	0.049	Dif
VR/ Mac-Run	0.045	Dif	0.063	No Dif
VR/ Control	0.001	Dif	0.003	Dif
Video/ Mac-Run	0.788	No Dif	0.600	No Dif
Video/ Control	0.104	No Dif	0.382	No Dif
M-Run/ Control	0.078	No Dif	0.114	No Dif

The Kruskal-Wallis and t-tests agree in most cases. They disagree for the Mac-Int/Video comparison, the VR/Video comparison, and the VR/Mac-Run comparison. For the Mac-Int/Video comparison, the t-test shows significance, while the Kruskal-Wallis does not and for the Video/Mac-Run the Kruskal-Wallis finds significance while the t-test does not. However, for these two comparisons, both methods are near the cut-off value of alpha = .05. Since an alpha of .05 is not a sacred number, there is justification to conclude that the delta score is significant. Therefore, the conclusion is that the delta score for the Mac-Int treatment is significantly larger than the one for Video and the delta score for the VR treatment is significantly larger than the one for the Mac-Run treatment.

The difference in the results between the Kruskal-Wallis method and the t-test method is more problematic for the comparison of VR/Video, since the difference in results is large. The Kruskal-Wallis shows a significant difference between VR and Video at an alpha of 0.049 while t-testing results in no significance with a probability of 0.239. The Kruskal-Wallis result will be accepted in this case because of a large variance difference between the VR and Video groups (4.4 vs. 12.1).

The results of Table 8 are illustrated in Figure 16 by drawing a line linking groups which are not significantly different from each other. The Mac-Interactive delta score is not significantly different than the VR delta score, but both of those groups have delta scores which are significantly larger than the other three groups. The delta scores of the Video, Mac-Run, and Control groups are not significantly different from one another.

Mac-Int VR Video Mac-Run Control

Figure 16: Oral Delta Score Significance

Table 9: Written Delta Test Comparisons

Media	Mac-Int	Mac-Run	VR	Video	Control
Delta Score	2.500	1.962	1.194	0.321	-0.571

Comparison	Writ t-test	T sig dif	Writ K-W	K-W sig dif
M-Int/Mac-Run	0.625	No Dif	0.587	No Dif
M-Int/VR	0.130	No Dif	0.094	No Dif
M-Int/Video	0.027	Dif	0.056	Dif
M-Int/Control	0.002	Dif	0.007	Dif
M-Run/VR	0.390	No Dif	0.350	No Dif
M-Run/Video	0.103	No Dif	0.113	No Dif
M-Run/ Control	0.012	Dif	0.023	Dif
VR/Video	0.188	No Dif	0.458	No Dif
VR/Control	0.006	Dif	0.030	Dif
Video/ Control	0.121	No Dif	0.271	No Dif

The same methods are used for exploring the written data. For the written delta scores, the Kruskal-Wallis and t-test methods agree in every case as can be seen in Table 9. Figure 17 shows a summary of the data.

For the written delta scores, there is no significant difference between the Mac-Int, Mac-Run, and VR groups. Mac-Int is significantly better than the Video and Control groups. Mac-Run and VR are not significantly different than Video, but they are significantly better than the Control group. For the written delta, Video is not significantly better than the Control groups.

Mac-Int Mac-Run VR Video Control

Figure 17: Written Delta Score Significance

Significance of Media

The media with high levels of interaction seem to be the most successful at increasing the oral test scores with VR and Mac Interactive being significantly better than the other treatments. Immersion did not seem to be important. This will be discussed further in a later section with conjectures as to why immersion may truly be important, even though they were not illustrated in this particular designed experiment.

Regarding the written test, interactivity seems to be important, but not as clearly as with the oral test. Mac-Int and VR are still significant, but the Mac-Run treatment was also as effective as the high interaction groups. This result agrees with the assumptions of the difference between the oral and written tests. Mental model building is not necessarily required for the written test and therefore interaction is not required to do well on the written test.

DAT Main Effect

Due to the logistics of the experimental design, the DAT scores were gathered only for the VR, Video, and Control groups. These groups were chosen as being on the extremes of the immersion/interactivity continuum. Table 10 shows the correlation of DAT to the oral and written pre, post, and delta scores regardless of media. Figure 18 shows the DAT scores plotted against the oral pre scores, oral delta scores (post score minus pre score), written pre scores, and written delta scores. The important information in this data is that the DAT score was not correlated to increase in score (the delta) for both the written and oral tests. This implies that DAT alone is not a significant indicator as to how a student will improve on the chemistry tests.

Table 10: DAT Correlations

	DAT
Oral Pre Test	.462
Oral Post Test	.488
Oral Delta Test	.163
Written Pre Test	.483
Written Post Test	.604
Written Delta Test	.342

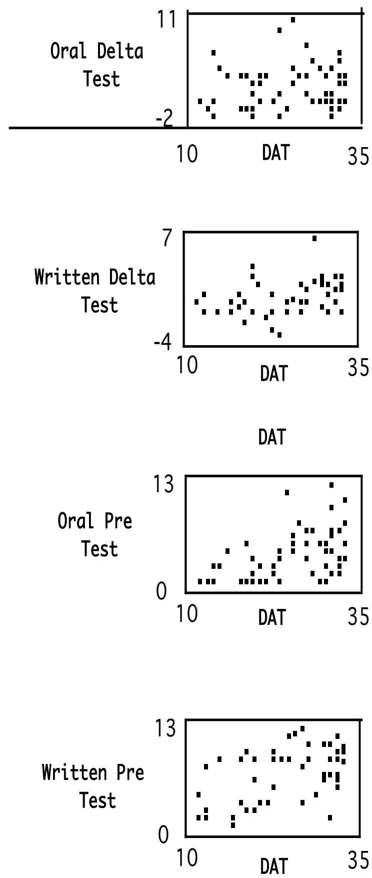


Figure 18: DAT Main Effect

A noteworthy observation is that no one who scored poorly in spatial ability scored well on the oral pre test, while some of these students performed well on the written test. There could be an interesting reason for this difference. Possibly, people who do not naturally have a good spatial ability can learn what is expected of them in the traditional classroom, but underneath do not really have a working concept of what they are allegedly learning. So, the students can learn how to fill out an orbital fill diagram, but without spatial ability, they do not really understand what that diagram means. This suggestion is offered in the spirit of exploration throughout this dissertation. Of course, there are many data points in those two graphs that represent students who have a high level of spatial ability but who also did poorly on the pre tests.

DAT / Media Interaction

To look for possible DAT/media interactions, Table 11 shows the DAT correlations when the data is divided into VR and Video groups. Figure 19 shows the DAT graphs split by VR and Video treatments. For both the oral and written tests, the correlations for the delta scores are small and similar across the two groups. The graphs show similar scattering of data points. This implies that there is no significant DAT/media interaction.

Table 11: DAT Correlations VR versus Video

	VR - DAT	Video - DAT
Oral Pre Test	.572	.298
Oral Post Test	.532	.444
Oral Delta Test	.126	.283
Written Pre Test	.558	.486
Written Post Test	.643	.748
Written Delta Test	.342	.403

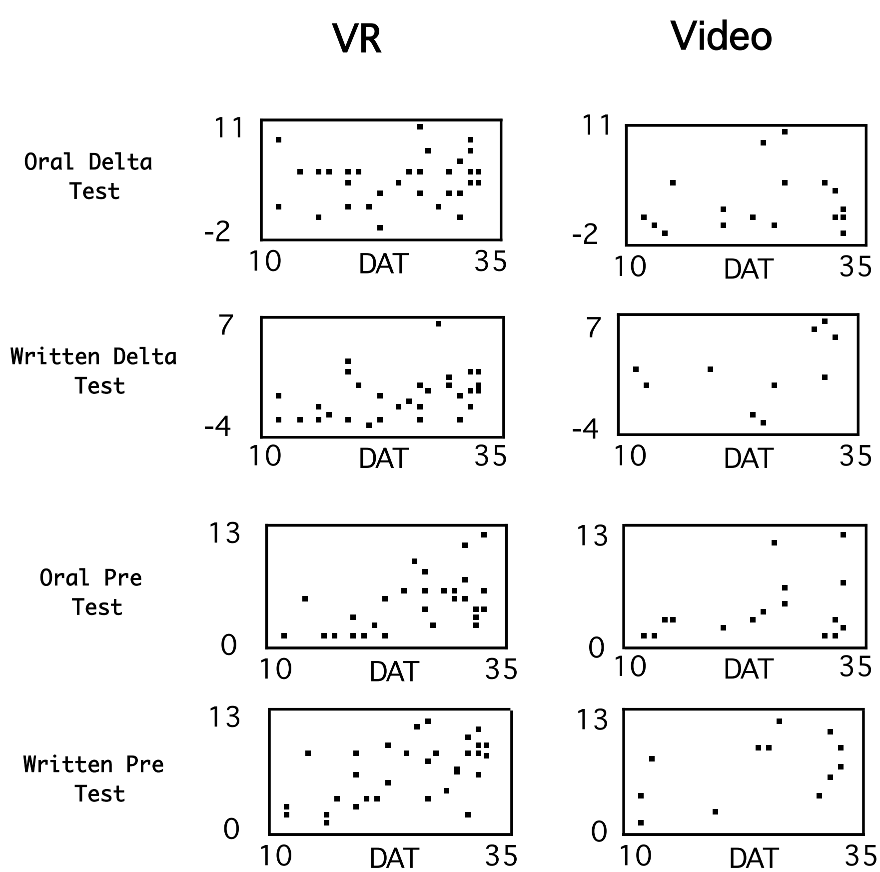


Figure 19: DAT VR vs. Video

With a lack of significance both as a main effect and as an interaction effect for both the oral and written tests, the DAT score does not seem to be a significant factor.

Long Term Retention

Although not included as part of the original hypothesis section, the interesting question for educators is whether the gains experienced by the students are retained after a period of time. To explore this, students who were in the VR, Video, and Control treatments were tested 3 months after their participation in the original study. The oral test was the same as before and the written test was very similar in form to the pre and post written tests.

All students who participated in the VR, Video, or Control treatments were invited to take another oral and written test battery. Most of the students in the control group participated again. However, not all of the other students who had participated in the other treatments were available or interested in continuing their involvement. The sub population who did participate were a representative sample of the whole potential population. Table 12 shows the results of a t-test comparison between the earlier scores of the group who participated in the long term study versus the earlier scores of people who did not participate. All of the numbers are far above an alpha of .05 which means that there is no significant difference between the two groups. All participating students were paid ten dollars for their involvement and were released from one class period. The testing was done at the students' high school during regular school hours. The oral test was the same one used for the pre and post oral tests previously taken. The written test was similar to the previous two written tests with the names of the atoms and molecules changed. Participation in this experiment consisted solely of taking the oral and written tests.

Table 12: Long-Term T-Test Probabilities

Medium	Oral Pre Mean	Oral Post Mean	Written Pre Mean	Written Post Mean
VR	.863	.964	.964	.820
Video	.268	.692	.751	.502

The means of the long term oral and written scores by media are shown in Tables 13 and 14. Graphs illustrating these numbers are shown in Figures 20 and 21. The long term means for the various media are not significantly different from each other for either the oral or written tests as shown in Tables 15 and 16. However, since this study is of an exploratory nature, there are some noteworthy points.

Table 13: Oral Long Term Means

Oral Test	D. of F.	Oral Pre Mean	Oral Post Mean	Oral Long Term Mean
VR	17	3.389	6.556	4.333
Video	16	3.412	5.059	3.824
Control	5	4.667	5.667	5.500

Table 14: Written Long Term Means

Written Test	D. of F.	Written Pre Mean	Written Post Mean	Written Long Term Mean
VR	17	6.556	7.556	7.028
Video	11	6.441	6.583	7.618
Control	5	7.417	7.083	7.750

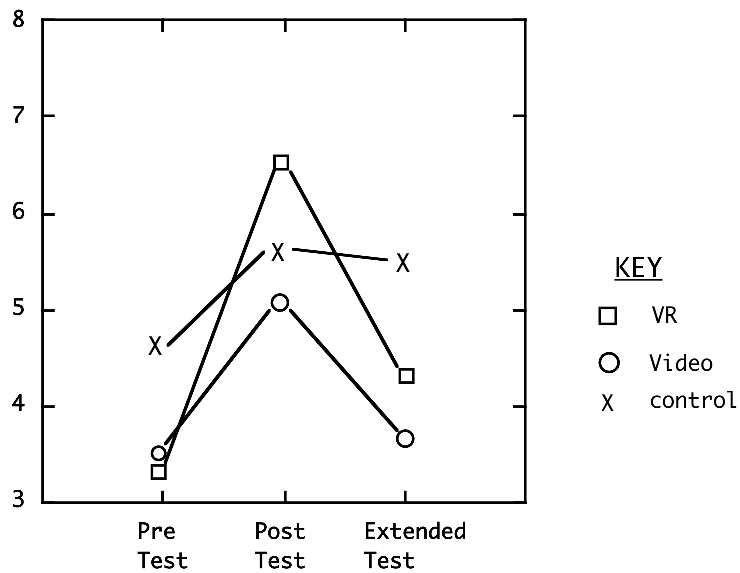


Figure 20: Oral Long Term Means

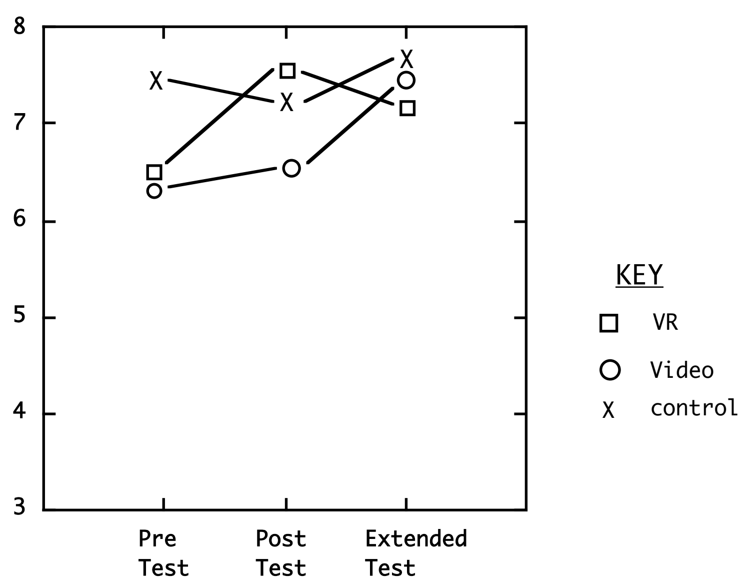


Figure 21: Written Long Term Means

Table 15: Oral Long Term Test ANOVA

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MEDIA	12.517	2	6.259	0.481	0.622
ERROR	493.971	38	12.999		

Table 16: Written Long Term Test ANOVA

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MEDIA	4.014	2	2.007	0.172	0.843
ERROR	444.376	38	11.694		

For the oral tests, the averages of all the groups are lowest at the pre test, rise with the post test, and then drop with the extended test, but not down to the original level of the pre test score. The group who were in the VR treatment suffered the largest drop in extended test score, but they were also the group who had gained the most immediately after the treatment. Levels of significance comparing pre, post, and long term tests are shown in Table 17.

Table 17: Oral Long Term T-tests

Oral Test	D. of F.	Pre/ Post T	Pre/ Post Prob	Pre/ Ext T	Pre/ Ext Prob	Post/ Ext T	Post/ Ext Prob
VR	17	6.333	0.001	2.411	0.027	-5.547	0.001
Video	16	2.313	0.034	0.503	0.622	-1.883	0.078
Control	5	2.236	0.076	0.773	0.474	-0.222	0.833

The significance of the pre, post, and extended oral tests for VR are important to note. While the extended test score dropped significantly from the immediate post test score, there is still significant improvement over the original pre treatment state of knowledge. Furthermore, although video showed an immediate improvement on the post test score, no long term improvement was maintained. From this data, the conclusion is that while no treatment caused the students to significantly maintain the increase on test score that happened immediately after exposure to the treatment, VR did result in a significantly higher test score than the students had before the study.

Table 18 shows the written test data. The only significance in this test data is the gain in test score between the pre and post tests for the VR treatment. The gain that was seen after the VR treatment was not maintained in the long term. The data from the extended written tests is more puzzling than the oral test data. The VR written data follows the trend of the oral data with a drop in test score for the extended test, but not to the original level of the pre test as seen in Figure 21. However, for the video and control treatments, a slight gain in written test score happens three months after the treatment. Fortunately, this confusing manifestation is not significant at an alpha level of 0.05 and can be contributed to variance in the data.

Table 18: Written Long Term T-tests

Writ Test	D. of F.	Pre/ Post T	Pre/ Post Prob	Pre/ Ext T	Pre/ Ext Prob	Post/ Ext T	Post/ Ext Prob
VR	17	2.766	0.013	0.833	0.416	-0.913	0.374
Video	11	0.420	0.683	2.018	0.061	1.767	0.105
Control	5	0.791	0.465	0.319	0.763	0.594	0.579

CHAPTER 4: Discussion

Main Conclusions

As will be recalled, the hypothesis of this study was that VR would be useful as an educational tool due to its high degree of interactivity and immersion. While the students in the VR treatment did significantly improve their post test scores over their pre test scores, the main result of this study was that interactivity and not immersion is the important factor in learning about atomic and molecular structure. This conclusion was due to the result that students in the VR and Mac Interactive treatments scored well on both of the tests. In most comparisons, their scores were significantly better than the Mac Run, Video, and Control groups. However, the VR and Mac Interactive students were not significantly different from each other, which leads to the conclusion that interactivity is the important feature. For both the oral and written tests, Figure 22 illustrates the comparison among the different treatments in terms of the delta, which is the average improvement between the pre test and the post test. Lines are drawn connecting treatments which are not statistically different from each other. A vertical line is also drawn dividing treatments whose post test score was significantly higher than the pre test score.

ORAL TEST

Media	Mac-Int	VR	Video	Mac-Run	Control
Delta Score	4.2	3.3	2.3	2.0	0.7

Significant | Not Significant

WRITTEN TEST

Media	Mac-Int	Mac-Run	VR	Video	Control
Delta Score	2.5	2.0	1.2	0.3	-0.6

Significant | Not Significant

Figure 22: Oral and Written Test Significance

The Mac Run and Video treatments, which should have had the same results for all of the tests, were not significantly different from each other for the oral test. However, they were significantly different from each other for the written test. Surprisingly, students in the Mac Run treatment scored as well on the written test as students in the VR and Mac Interactive groups. The Video treatment group did not significantly improve on the post written test as compared to the pre written test. This implies that immersion and interaction were not the only factors involved in influencing improvement on the written test. One possible factor is the original classroom instruction that the students received. The written test would be more susceptible to this factor, since that test was meant to mimic the classroom test. So, although there was no significant difference among the two different school populations in the pre test score, the Mac students might have been remembering something they had been taught while experiencing the Mac chemistry world, while the other students were really learning or not learning the subject during their experience of the chemistry world.

The spatial ability factor, as measured by the DAT score was not significant for the oral test and only marginally significant for the written test. No conclusions can be drawn from this data about how spatial and non-spatial learners create and manipulate their mental models.

For the long term study of the VR, Video, and Control treatment students, none of the groups retained any of the gains that they might have made in the post tests. However, while the VR students did not maintain their significant improvement on the oral test, they did not slip back to their original pre test level. The VR extended oral post test score is significantly higher than the VR oral pre test score.

Discussion Of Results

The results of this study have not shown VR to be superior to other methods of instruction, namely an interactive Macintosh method. However, interactivity, an inherent part of VR, has been shown to be important. I had hoped that the immersion aspect of the VR treatment would make the chemistry concepts more concrete than the illustrations in the Mac Interactive treatment. To allow for the possibility that VR is significantly better than Mac Interactive despite the presented evidence, I need to examine the differences between the two treatments that might have skewed the study. I have identified five areas of difference, which are: training, world design, assessment, hardware resolution, and student population.

The most obvious difference between the VR and Interactive Mac treatments is that everyone in the VR treatment was experiencing that medium for the first time, while no one in the Mac treatment was new to the Macintosh computer. I did not train the VR participants to a level of expertise, so they were given the cognitive task of navigating in VR along with learning the chemistry lesson. Although I also did not train the Mac students in the use of the computer, they all used the tool easily. As I ran the experiment, it was clear to me that the VR students were struggling with maneuvering in the virtual world while trying to remember what needed to be done to build the virtual atom. The Mac students were able to concentrate exclusively on building the atom. Evidence of this lies in the difference of error rate for the two groups. I kept track of how many times a student made a mistake in setting the correct energy level and/or spin. Typically the error was that they forgot to change the setting as opposed to setting the indicator to the wrong level. The VR students made many more errors than the Mac students. Table 19 shows the error rates for the two groups. The VR group consistently made more errors than the Mac group. Only one third of the VR group made no errors while one half of the Mac group made no errors. The likely explanation is not that the VR group was less capable, since their pre test scores were not significantly different from the Mac group, but rather that the VR group had to concentrate on additional tasks. This drew attention away from the task of learning about chemistry. Further study of the use of VR in education should explore the importance of familiarity with VR itself.

Table 19: Error Rates

	N	Spin Error			Energy Error		Any Error			
		0	1	2	0	1	0	1	2	3
Mac	14	79%	14%	7%	71%	29%	50%	43%	7%	0%
VR	33	58%	33%	9	58%	42%	33%	42%	21%	3%

Another area of difference between the VR and Mac groups also relates to the relative newness of VR. Designing a virtual world to take advantage of the immersion aspect of VR is non-trivial. In the same way that early filmmakers merely recorded stage plays without using the uniqueness of the new medium, my virtual chemistry world did not dramatically use the immersion capability. I believe that I failed to use the full potential of immersion in the world. If VR has the capability of providing an immersive experience, but immersion is not exploited, then VR theoretically has no benefit over the Interactive Mac. A future study could creatively use immersion in a virtual world in order to analyze VR. One chemistry world example is to somehow highlight and encourage viewing the atom and molecule from various perspectives including from inside the structure.

Assessment was another area that could have been improved in this study. The main problem was asking students to sketch a 3D object on a

2D piece of paper. The VR students saw the orbitals in 3D and were asked to draw them on a 2D piece of paper. The Mac students saw the orbitals on a 2D screen and were asked to draw them on a 2D piece of paper. Therefore, the Mac students were at a clear advantage since they did not have to translate the image they saw. Late in the study, I spoke with a VR student who felt that her understanding of the shape of orbitals had greatly increased, but who had done poorly on the test. I asked her about this disparity and she answered that she understood it in her mind, but could not draw something like that on a piece of paper. A future study could try different assessment techniques. One option would be to have the students sculpt the shape of the orbitals in some 3D medium such as clay, instead of drawing the shape. Another less intensive method of assessment would be to show several 3D models and have the students choose the correct model for a particular orbital.

The resolution difference between the Macintosh monitor and the VPL EyePhones might have influenced the results of this study. Students in the VR treatment wore low resolution EyePhones and saw “fuzzier” objects than those in the Macintosh group. This might have kept the students from feeling truly immersed in the virtual chemistry world, thereby reducing the VR experience to the low immersion treatment of the Macintosh.

Finally, another area of difference between the VR group and the Mac group was in student population. The two groups came from different schools and therefore had different chemistry classes and teachers. This was an unfortunate experimental design due to reasons outside of the researcher’s control. Obviously, any future studies should strive to eliminate any unnecessary confounding factors like this. How much this difference affected the outcome of this study is unknown.

These differences between the VR and Mac treatments warrant strong consideration when drawing any conclusions from this study. As a final note, I watched many students go through the various technologies. The most enthused students I saw were the ones who experienced VR. Certainly VR was exciting and new for the students, but more importantly, I witnessed “a-ha” moments from many of them. One student scored zero on his pre-test. While he was in the VR world, he kept saying over and over, “oh, that’s what the teacher meant.” On the post-test, he scored a zero. I don’t know what knowledge he gained, but I am convinced that with VR, he understood something he didn’t know before.

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Appendix A: Written Pre Test

Name _______________ PRE-TEST

Optional Questions:

Age ____ Grade Level _____ Gender _____ Race ___________

Chemistry Problems

Example of orbital diagram for He:

O

Example of electron configuration for He:

$1s^2$

Prob 1)

Draw an orbital diagram and write the electron configuration for:

Mg

How many protons does Mg have?

How many neutrons does Mg have?

Prob 2) Write the electron configurations for the following element:

bromine

prob 3) Draw the orbital diagram, and write the electon configuration for the following element:

potassium

Prob 4) For the following electron configuration of a neutral atom, determine the name of the element listed and determine if the configuration as written is the ground state or an excited state:

$1s^2 \quad 2s^2 \quad 2p^5 \quad 3s^2$

Prob 5) For the following electron configuration of a neutral atom, determine the name of the element listed and determine if the configuration as written is the ground state, an excited state or if it is an impossible configuration:

$1s^2 \quad 2s^2 \quad 2p^6 \quad 4s^1$

Prob 6) Draw the electron dot structure for the following molecule:

H_2O

Draw the shape of H_2O:

Appendix B: Written Post Test

Name _______________ POST-TEST

Chemistry Problems

Example of orbital diagram for He:

O

Example of electron configuration for He:

$1s^2$

Prob 1)

Draw an orbital diagram and write the electron configuration for:

S

How many protons does S have?

How many neutrons does S have?

Prob 2) Write the electron configurations for the following element:

arsenic

prob 3) Draw the orbital diagram, and write the electon configuration for the following element:

fluorine

Prob 4) For the following electron configuration of a neutral atom, determine the name of the element listed and determine if the configuration as written is the ground state or an excited state:

$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $4s^2$ $3d^3$

Prob 5) For the following electron configuration of a neutral atom, determine the name of the element listed and determine if the configuration as written is the ground state, an excited state or if it is an impossible configuration:

$1s^2$ $2s^3$ $2p^5$

Prob 6) Draw the electron dot structure for the following molecule:

NH_3

Draw the shape of NH_3

Appendix C: Oral Test

Name:___________________ ORAL TEST INTERVIEW

Sodium Electron Configuration

$1s^2$ $2s^2$ $2p^6$ $3s^1$

What is an orbital?

What is / ?

What is \ ?

What is the difference between / and \?

What is O (1s)?
What is O (2s)?
What are O O O (2p)?

What is the difference between O (1s) and O (2s)?

Is there a difference between O (2px), O (2py), and O (2pz)?

If so, what is the difference?

Do the spins of the first electrons in O (2px), O (2py), and O (2pz) need to be different, the same, doesn't matter?

What is the path of the electron in the orbital?

Why can the 2p orbital have 6 electrons when the 1s and 2s orbitals can only have 2?

(on back of sheet)

Draw the shape that this [O (1s)] represents.

Draw the shape that this [O (2s)] represents.

Draw the shape that these [O (2px) O (2py) O (2pz)] represent.

Secondary questions:

What is the difference between two electrons in the same orbital?

Draw the shape of a 1s orbital:

Draw the shape of a 2s orbital:

Draw the shape of a 2p orbital:

What is the difference between 1s and 2s orbital?

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Ph.D. in Mechanical Engineering, University of Washington, 3/96. Dissertation: Water on Tap: The Use of Virtual Reality as an Educational Tool.

Master of Science in Industrial Engineering, University of Washington, December 1988. G.P.A. 3.8 Thesis: Use Of Design Of Experiments In The Improvement Of A Production Line.

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WORK EXPERIENCE

Research Associate - Human Interface Technology Lab, March 1991 to March 1995. University of Washington, Seattle, WA.

Coordinated Education Project, which involved over 150 students in VR world building. Numerous lectures on VR related topics. Taught economics and assisted with statistics.

Acting Manager Engineering Operations - Network Facilities, July 1990 to January 1991. US West Communications, Bellingham, WA.

Directly managed four engineers, two clerical support personnel and 15 million dollar budget. Responsible for developing and implementing a fiber network in the metropolitan area of Bellingham, including establishment of fiber rings and hubs.

Manager Engineering - Network Facilities, June 1987 to July 1990. US West Communications, Seattle, WA.

Managed and planned the feeder network in several major wire centers. Determined long range economic solutions for facility needs. Designed distribution facilities for various wire centers. Responsible for coordinating projects with customers, contractors, and government agencies.

Pre-Professional Industrial Engineer, July 1985 to September 1985 and April 1986 to July 1986. I.B.M., Endicott, New York.

Designed and conducted fractional factorial and response surface experiments on a production line. Analyzed experimental data and recommended process control system.

Co-op Industrial Engineer, January 1984 to June 1984. Jet Propulsion Laboratory, Pasadena, California.

Studied human factor concerns in the design of a direct command language for a new Federal Aviation Administration (FAA) computer system. Compiled dictionary of terms.

Co-op Industrial Engineer, March 1983 to September 1983. Associated Grocers, Inc., Seattle, Washington.

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