University of Alberta

3D Simulations for Physics Education, an Interpretive Study

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Education

in

Instructional Technology

Department of Educational Psychology

Edmonton, Alberta

Fall 2005

Your file Votre référence
ISBN: 0-494-09096-0
Our file Notre référence
ISBN: 0-494-09096-0

Dedication

To

Mom and dad, you have always traveled with me in mind and spirit. Your example, support, and encouragement have always given me strength to continue challenging myself with new adventures, your love is my beacon whenever I get lost.

Efren and Rommel, my life would not be complete without you; you are my inspiration, the music of my soul.

My grandparents, aunts, uncles, and cousins, for your love and all the wonderful moments together, wherever I go, you are always on my mind.

Jim, without you I would not have learned more about me.

All my friends, you are the light of my life, and the proof that this life is worth living.

You, for keeping my heart beating.

Abstract

This interpretive study provides insight into participants' experiences and interactions with a 3-D simulation for learning concepts of physics, specifically, the properties of light and the wave model of light. The design and production of the 3-D simulation used in the study was also an important component of the research.

To fully capture the interactions of the participants using the 3-D simulation I employed various methods. I organized individual sessions that consisted in the video and audio recording of the interactions, followed by semi-structured interviews.

The study showed that students were excited about the visual features of the 3-D simulation, and their impressions reflected interest in the use of 3-D simulations for learning physics. The final chapter includes my reflections on the meaning of their answers, what I learned during my experience as novice researcher, and recommendations for future research.

Acknowledgements

This thesis would not have been possible without your support, therefore I would like to say thank you to:

Dr. David Mappin, for your immense support, your words of wisdom and for helping me reach the finish line.

Dr. Craig Montgomerie, for the job opportunities, being part of the RACOL project was a wonderful experience.

My advisory committee: Dr. David Mappin, Dr. Craig Montgomerie, and Dr. David Geelan, for your time and invaluable comments.

To the school administration, the teacher and the participants of this study.

Dr. Robin Everall, for your encouragement and words of advice.

Table of Contents

List of Figures

Chapter One

Introduction

> "The visual element should not merely be present in each area of knowledge separately, but this concern should cut across departments and disciplines, be handled with similar criteria in the different areas and add up to the formation of a unified mind in which the various realms of knowledge combine to one comprehensive world view."
>
> (Arnheim, cited in Moorhouse, 1974)

I have been attracted to three-dimensional images (3-D) for as long I can remember, but my interest in 3-D computer graphics grew even greater in 1997 when I first observed a computer-generated animation in the classroom in detail. I was taking my last multimedia course of my baccalaureate program, which included 3-D and virtual reality as part of the curriculum. The 3-D animation was Tin Toy (Pixar Animation Studios, 2005) one of the first commercial computer animations produced by Pixar.

The animation was about Tinny, the tin toy, and a toddler. The story goes something like this: At the beginning, Tinny finds himself in the middle of a room when he sees a toddler coming towards him. The toddler stops and sits right in front of him and starts playing with his toys. Tinny observes with anxious eyes how the toddler shakes and drools upon his toys; he looks at the camera and slowly moves away from the toddler. Unfortunately, the tin instruments attached to his hands and body make very loud sounds that cause the toddler to go after him. Tinny hides under the couch and realizes with surprise that there are more toys hiding. In the meantime, the toddler falls in his effort to reach the couch and starts crying. Tinny feels bad and goes out to distract him. The toddler plays with Tinny until he finds a new toy, a paper gift bag, which he uses to cover his head. The animation concludes with Tinny following the toddler once again to get back his attention.

I was very impressed by the details in the graphics of what I considered a landmark 3-D animation, taking into account that when I saw this animation it was already nine years old. The characters had a cartoon-like look, but it was interesting to see the lifelike representation of the environment. I still remember how, after watching the animation, the professor wanted us to go through it repeatedly and observe all the elements thoroughly. He asked us to pay special attention to the details, and, how, by manipulating lights, shadows, and colors, the creators were able to design an environment rich in depth, making it possible for the featured characters and objects to emulate the physical characteristics of real ones.

As students in 1997, we were merely admiring and superficially exploring 3-D software because the lab computers did not have the capacity for sophisticated and complex projects. I remember that for our final assignment we were asked to work in teams of two, and our project was a very simple 3-D teapot with an animated lid.

The software we normally used for graphic design was oriented for two-dimensional graphics, and there was no real need for 3-D design. If I wanted some three-dimensional elements in my layout I had to do it by manipulating lines, colors tones and gradients, and it would normally take me long hours to achieve a decent solution. In those days, a graphic designer needed to be more skilled with technical pens, paper, and a cutter than with computers. This situation has changed enormously. I witnessed my own transition from being proficient in cutting and pasting paper (slowly learning to design using computer software) to the point where I was designing almost everything with the computer. The digital design era was becoming a reality and I was looking forward to the future of computer graphics, although I never imagined myself doing research on how useful 3-D simulations might be as tools for learning.

The turning point in my academic life was working at the Tecnológico de Monterrey Virtual University. There I worked with professors, TV producers, and instructional designers in the development of educational solutions for distance education, and even when tight schedules did not give me the time to learn software that was not required for the projects we were working on, I always left some room to play around with 3-D software such as Infini-D and Extreme 3D. I never created anything complex but I had lots of fun.

The experiences I obtained from collaborating with instructional designers inspired me and had a strong influence on my decision to select instructional technology as a field to do my graduate studies. Hoping that my skills as a graphic designer would be an asset, I enrolled in the program at the University of Alberta.

While taking courses, I worked in the multimedia laboratory providing support for students interested in using 3D Studio Max. It was then when I started brainstorming the possibilities of doing research on 3-D for learning.

The idea took a more serious turn when I participated as a research assistant for the Rural Advanced Community of Learners (RACOL) project. The RACOL project, which was a collaborative partnership, developed a model of teaching and learning to implement and facilitate the use of broadband networks and advanced digital technologies that resulted in an operational asynchronous/synchronous system for northern Alberta. As part of the job I visited some of the schools participating in the project. There I met the teachers who were working with the videoconference system and this encounter really revealed the possibilities for doing research in their environment.

3-D Simulations Today

Rapid advances in technology have made desktop computers more accessible and more powerful. They have gradually gained acceptance in many areas of our lives and nowadays it is almost unimaginable to forecast a future without them.

In the realm of visual communications, desktop computers are an essential tool for the design and development of a variety of innovative graphics and multimedia solutions. 3-D simulations are a part of these innovations and they are starting to be widely used in the film industry, broadcast television, multimedia, game development, industrial design, engineering, the health industry, training, and research (Giambruno, 2002).

Despite their popularity in many areas, the use of 3-D simulations as tools for learning is still not very common and the use of those simulations that do exist is limited. Some of the factors that have influenced this situation are:

a) Access to desktop computers in the classroom which varies from school to school (Looker & Thiessen, 2003)

b) The ongoing debate about the benefits of using computers for learning (Wiske, 2001)

c) Teachers and instructors' time limitations and other concerns about the use of technology that affect the testing and implementing of new tools for learning (Neal, 1998).

While looking for information about 3-D simulations, I noticed that the availability of 3-D material in general was vast. I found many books related to 3-D software, programming, and modeling, and articles focused on the latest algorithms and rendering systems. The Internet provided me with the best examples of 3-D resources, from entertainment to educational, and from the simplest to the most complex. For example, I found 3-D geometrical models, a detailed 3-D simulation of the human body, and virtual representations of cities and places (Anatomy TV, 2005; Glass House Studio, 2005). I noticed too that the Internet had some advantages over books and articles. Companies and educational institutions were able to share information about their older and more recent 3-D projects that otherwise would be expensive to publish, and, besides, one could often look at their more recent developments.

It was evident that the creation, design, and production of 3-D simulations, once an exclusive activity for technology developers, computer scientists and private sector researchers, was now an activity accessible to the general population and educational institutions. The cost of high performance computer systems had decreased, and the software was available at a more reasonable price.

Today there is a growing interest within the educational community in the use of animations and simulations and other multimedia for learning. I found that academics from various fields were starting to do research on their benefits and their use in the classroom and some studies have shown promising results for animations and simulations as tools for learning. Peña & Alessi (1999) in a comparison of a computer-based simulation with computer-based text affirmed:

> Simulations are particularly useful in helping students to connect their symbolic learning in school to real-world situations because they can represent abstract concepts in a concrete manner.... They give students access to the unobservable features in a problem situation. For example, it is possible to observe light shining through a lens but it is not possible to determine the exact pattern of the light rays nor at what point they converge or diverge. Thus, simulations allow for a more detailed analysis of phenomena and provide greater control over phenomena than is available through casual, real-world observation. (p. 442)

Whether developed with the use of sophisticated applications or with open source programming codes, simulations are becoming an attractive and feasible alternative to communicate instructional content. Good examples of the fast growing number of these tools for learning maybe found at the Multimedia Educational Resource for Learning and Online Teaching web site (MERLOT, 2005).

Simulations with three dimensions as tools for learning are more recent and it is more common to see 3-D features within virtual reality projects. This is because virtual reality has other features that seem very attractive for diverse educational purposes, from testing its applications to helping students with special-needs (Bricken & Byrne, 1993; Neale, Brown, Cobb, & Wilson, 1999). By taking advantage of high-speed networks, diverse projects have developed collaborative environments that facilitate people participating over distances. World heritage, for example, has become a common virtual reality endeavor because it allows the user to be in places that no longer exist. "...virtual environments can bring back a sense of the place, the history, the architecture, and be used as an educational tool" (Pape, Anstey, Carter, Leigh, Roussou & Portlock, 2001).

Purpose of the Study

The purpose of my study was to gain insight into the usefulness of 3-D simulations. I wanted to find out first hand, from the students' perspective, how useful 3-D simulations were as tools for learning.

I strongly believed that 3-D simulations had features that made them a valuable tool for assisting learning along with the growing selection of other multimedia resources. 3-D simulations could be useful in helping students visualize information where depth cues are essential, such as in understanding situations taking place within our three-dimensional world. For example, in most textbooks and other publications, scientific phenomena are commonly represented using linear diagrams (see Figure 1); 3-D graphics could provide a better way to illustrate them, when spatial references might be essential to understand the phenomenon.

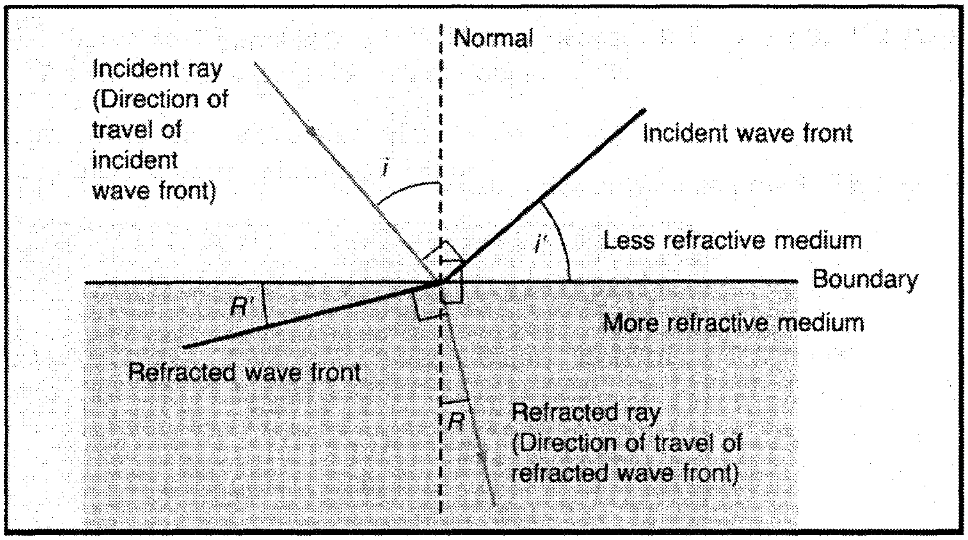

Figure 1. Diagram of the phenomenon of refraction between two mediums

I planned to observe the participants' experiences while interacting with the 3-D simulation and to listen to their impressions and comments to find out whether these innovative resources offered a visually rich learning experience. I wanted to know if the 3-D simulation helped them to improve their understanding of the subject, in this case some of the properties of light.

This study also included the design and development of the 3-D simulation used by the participants. Producing the 3-D simulation gave me a better opportunity to do my research in a holistic way. I considered that: a) I would have a more fulfilling learning experience, b) more control over the curricular and visual content, and c) more knowledge for fixing and troubleshooting in case of any unexpected situation.

Significance of the Study

Many times we do not have the ability or the time to scrutinize our choices when it comes to multimedia resources, computer systems, networks, or learning management tools, because we are caught up in the day-to-day pressure of producing and delivering educational experiences. While I was learning more about instructional technology I found myself puzzled about the value we place on some educational resources over others, the circumstances that motivate us to use them, and the rationale behind our values and decisions.

Considering that human and financial resources have been poured into the development of innovative educational applications (games, multimedia, virtual environments, interactive web sites, and animations) and their improvement has been driven by the best intentions to support educators and help students, research on how useful 3-D simulations are as tools for learning could be very beneficial. If there is enough support for the development of 3-D simulations, their use could increase in classrooms and other academic environments ensuring the establishment of best practices, as has happened with other tools for learning (Van Vliet & Specht, 1998; Stith, 2004; Siskos, Antoniou, Papaioannou & Laparidis, 2005).

Most of the studies that have dealt with the use of computer simulations and other media for learning have looked for answers through quantitative methodologies (Dekkers & Donatti, 1981; Rieber, 1990; Gokhale, 1996; Swaak & de Jong, 2001), and very few were based on three-dimensional graphics (Schonhage, Ballegooij &Eliens, 2000; Cockburn & Mackenzie, 2002). By doing qualitative research on 3-D simulations for physics education, I was hoping to contribute to the increasing (but still not sufficient) amount of information about these innovative resources as tools for learning from an interpretive perspective. At the same time, I believed that educators needed more choices, the same variety of choices as when selecting a textbook, which depends on the educator's taste and teaching style (I have seen that what makes a book great for one teacher is not enough for another).

In addition, an important number of researchers are oriented to the technical and technological side of 3-D simulations (e.g. Sandin, Margolis, Ge, Girado, Peterka & DeFanti, 2005; Krishnaswamy & Baranoski, 2004, and Zheng & Murata, 2000), which is important for the continuous development of 3-D computer graphics. However, their efforts are not intended to explore the use of 3-D graphics and simulations in an educational environment. This study intended to discover the implications of using 3-D simulation in an educational setting.

Research Questions

To gain some insights into the usefulness of 3-D simulations for learning several questions guided me:

1. What interactions take place when high school students use the 3-D simulation?
2. What are the high school students' impressions after experiencing and exploring the 3-D simulation?
3. What are the students' perceptions of the usefulness of the 3-D simulation and its educational content for learning?

The Research Study

To pursue these questions I designed and produced a 3-D simulation on the properties of light for high school physics. Chapter two reviews the literature that covers 2-D and 3-D computer graphics, simulation and virtual reality, as these topics are closely related. In chapter three, I write about the methodology and the methods I used to capture the participants' experience with the 3-D simulation.

In chapter four I describe the process of researching, designing and producing the 3-D simulation that was used for the study. Chapter five narrates my findings and my experiences as a researcher. Finally, chapter six discusses what was learned, and my insights into future research for 3-D graphics for learning.

Chapter Two

Review of the Literature

Research on the use of 3-D simulations for instructional and educational purposes is still not extensive. In this review of the literature I describe research on computer-generated media related to 3-D simulations, including 3-D graphics, virtual reality, and animation because I believe there is a close relationship between these new technologies and the definitions of them by various authors overlap. I found a substantial amount of research oriented to technology breakthroughs and technical specifications with detailed documentation of applied test runs, and descriptions of innovative features, and their potential for future applications.

I have organized my review in four topics: (1) Computer graphics: two-dimensional (2-D) and three-dimensional (3-D); (2) Computer Simulations (3) Virtual Reality; and (4) Animations for learning.

Computer Graphics: 2-D and 3-D

Throughout history we have employed drawings, paintings, schematics, and all kinds of two-dimensional graphics to represent our interpretation of the world and to leave memories of these interpretations. Sometimes when we find that verbal or textual descriptions are insufficient to express our ideas it is easier to explain them using visual aids like drawings or diagrams. Pictures, for example, contain a great deal of information, giving meaning to the phrase "a picture is worth a thousand words." For some situations the use of pictures and graphics is far more informative than describing a situation or a place with words.

The use of graphics complements instruction because it facilitates interpretation. Cyrs (1997) states that the use of visual information helps to provide more meaning to words, facilitating the relationships and connections between ideas and concepts. For Cyrs, pictures, graphic symbols, and verbal symbols are visual thinking elements.

Today computers make great tools for the creation of graphics with two or three dimensions, animated, coloured, and more. However, there is a difference between 2-D and 3-D computer graphics. Most of the computer software we use for everyday activities (e.g. Microsoft Office®, AppleWorks®, WordPerfect®, and others) has integrated drawing applications that, with the help of lines, allows us to create two-dimensional graphics represented by height (y) and width (x).

3-D graphics incorporate another dimension: depth (z), which allows us to see images in the computer in the same perspective in which we see them every day. We can see these 3-D graphics through a computer display, and Giambruno (2002) claims that such 3-D graphics are not in fact three-dimensional; they are a distorted truth because in reality 3-D graphics are two-dimensional representations of three-dimensional elements. The mathematical algorithms in the software make possible the integration of geometric shapes, cameras, and lights to generate a simulation of our world. 3-D computer graphics "are generated by constructing a virtual 3-D model which is then imaged, employing a physical simulation of illumination in three-dimensional space" (House, 1996).

Figure 3 shows the comparison of two 3-D cubes created with two different applications. The cube at the top was drawn with 2-D software using four squares, and to give a sense of perspective I had to modify each corner, which is one of the disadvantages of drawing three-dimensional objects with 2-D software (the red arrow shows one of the unmodified corners). The cube at the bottom was generated with 3-D software, and it was very simple to create because the software calculated the position of the cube in space automatically.

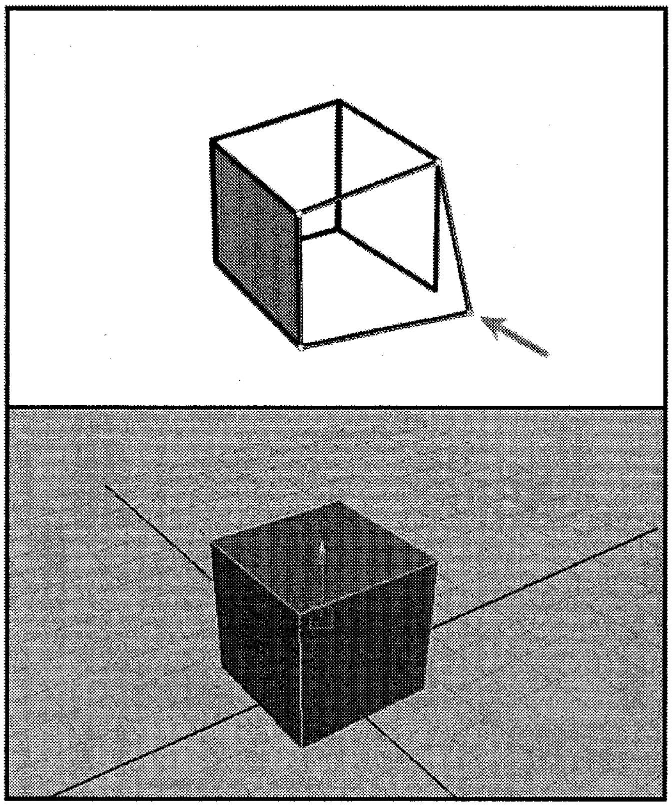

Figure 2. Comparison between graphics generated with 2-D and 3-D software

Even when it is possible for two-dimensional software to create 3-D objects with volume and perspective by managing lines, shadows and color shades, it is not as efficient and visually attractive as when designed with 3-D software.

For any 3-D application to successfully accomplish a reasonably accurate visual simulation of our space, House (1996) explains that a 3-D graphics system can be organized into three major components: scene specification, rendering, and image storage and display. In his explanation, scene specification is the software's internal 3-D simulation of space, rendering is the use of mathematical algorithms to transform a 3-D scene into a two-dimensional image; and image storage and display is the capacity of the software to store and transmit the rendering making it available to be displayed and printed.

3-D products have reached the education field and, as with any other new tool for learning, we are starting to wonder whether 3-D is better that 2-D. I believe there should be no comparison because both kinds of graphics have their purposes. What we have acquired is the choice of using 2-D or 3-D according to our instructional needs. Much of the research reviewed is focused on 3-D and 2-D interfaces and their applications, but questions on learning outcomes have been left unanswered.

An application note from Gelband, Weber, and Fryer (1998) described the challenges and benefits of revamping an existing 2-D game into a real-time 3-D experience. The 3-D title was once a 2-D puzzle solving game called Think Quick! which is now LogicQuest, a 3-D educational software program for elementary school. This puzzle solving game challenges children to negotiate a series of mazes and build robots to unlock the door to the next level. The game also gives children the possibility of building their own mazes. According to the evaluators, adding 3-D features offered a richer learning experience, which included increased engagement, development of spatial skills, and a natural and more intuitive interface. "The product's 3D nature lets players move through and explore their worlds (rather than simply look at them). They can experiment with natural design and science principles, including gravity and other spatial or visualization problems occurring in their environments" (Gelband et al., 1998). Unfortunately the educational value of adding 3-D features to the game was never tested. It would have been interesting to see what children thought about the change from a 2-D world to 3-D world.

In a study on 3-D gadgets for business visualization, Schonhage, Ballegooij and Eliens (2000), established how complex it is to compare 2-D with 3-D. The goals of the study were to evaluate the strengths and weaknesses of a 3-D interface prototype for visualizing business processes. While testing the 3-D interfaces of the prototype they realized that people with computer experience obtained higher scores than people with little or no experience. Animation, manipulation, and multiple perspectives were highly appreciated by the participants, whereas speed, control and acceptance were barely satisfactory. Researchers received positive feedback on the ability of the interface to represent the information in a 3-D space. According to the authors, the 3-D interface was more capable of visualizing past, present, and future simulated data in comparison with its 2-D counterpart, which was only able to represent past or present data at a single time in a linear layout.

Garg, Norman, Spero and Taylor (1999) in a study of learning anatomy wanted to evaluate the effectiveness of a 3-D computer model that provided multiple views of the carpal bones by testing students' spatial ability. The authors presumed that a 3-D model (in comparison to the standard views found in an anatomical atlas) would facilitate the understanding of the spatial relationships of the bones under the skin, which is clinically important for examination and treatment of patients. A randomized single-blind controlled study was performed; a group of 49 first-year medical students with no previous anatomy knowledge were randomly assigned to receive one of the two types of instruction, 3-D multiple views (MV) and 2-D standard key views (KV). The result found no significant differences in spatial learning. Although there is no explanation for the authors' rationale for wanting to provide the students with more views than the four found in an Atlas, it is possible that the use of 3-D graphics was not necessary in this context.

Since many studies on the relationship between learning and 3-D graphics are still focused on the implementation of the technology, claims that 3-D graphics facilitate learning are still questionable, and their development should consider other aspects besides the aesthetic one. The use of 3-D graphics began recently, and, as with other current research on new multimedia, research in this filed should yield more knowledge on issues such as the usefulness of 3-D graphics as tools for learning and best practices for their use.

Computer Simulations

Boundaries between the definitions of "simulations" and "virtual reality" are hard to establish as many times people use the terms interchangeably. The meaning of each concept is sometimes related merely to the context in which it is used. For example, McLellan (1996) has used the term virtual environment as synonymous with the Line-Oriented Flight Training (LOFT) simulator, a training program to which the author pointed as an example of situated learning perspectives.

Heinich, Molenda, Russell and Smaldino (2002) define a simulation as "an abstraction or simplification of some real-life situation or process." Smith (1999) defines simulation as the process of designing a model of a real or imaginary system to study or experiment with, and to understand the model behavior to evaluate best operation practices. He comments that exact representations of actual systems are almost impossible to achieve, and this limitation constrains us to design with a degree of fidelity that has to be specific to the situation for which the simulation is required.

To simulate a situation or to teach by example is a technique that has been around for some time. Gredler (2004) refers to the beginnings of the use of simulations back as far as the 1600s and 1800s, when war would force armies to simulate military situations for strategy planning. In the case of computer simulations Smith (1999) notes that the late 1950's were the landmark for the development of simulation programs predominantly oriented for the military and the manufacturing industry. In the last decade this interest has spread to other areas of education (engineering, architecture, computer sciences).

Simulations vary in design, features and purposes. They can be two-dimensional or three-dimensional, but, in general, they are intended to: simplify situations and phenomena otherwise impossible to observe in normal conditions (for example, DNA sequence and molecular behavior); to allow the safer practice of high-risk training activities (for example, pilots and surgeons); and to enhance learning by allowing the user to participate in decision-making and role-playing activities (for example, school administrators and business managers).

Nance and Sargent (2002) categorize simulations based on their objectives: (1) system analysis, which reflects the early work in simulations oriented to management science and operations research; (2) education and training, oriented to the understanding of concepts and the behavior of the application of the concepts learned; (3) acquisition and system acceptance, where the simulation is intended to evaluate the system's features, performance and possible contributions to a larger system; (4) research, involving the development of virtual environments in which system components can be tested, or individual and group behaviors can be studied; and (5) entertainment, which is more recent and features interactive activities for pleasure and enjoyment.

Based on specific learning principles, Gredler (1996) categorizes simulations in two types: experiential simulations and symbolic simulations. The first allows the participant to take a role and execute actions based on problem-solving strategies. It is oriented to simulating real interactions in predetermined environments in which the participant's decision-making has an impact in the outcome. The second, symbolic simulation, a dynamic representation of the function or behavior of a system or process, and the participant does not take an active role, although it is expected that interaction between the participant and the simulation takes place. Symbolic simulations are also categorized by their nature and characteristics as data-universe simulations, system simulations, process simulations and laboratory-research simulations.

Simulations as Tools for Learning

The use of simulations for learning is not extensive but has increased in the last decade. Both experiential and symbolic simulations are finding a place given their flexibility and their capacity to provide students with situations and scenarios that sometimes are impossible to have available in the classroom. During the time I was deciding on a topic for the 3-D simulation I had the opportunity to talk with a biology professor. We talked about my idea of three-dimensional simulations as tools for learning, and he told me how he used to build wood models when he wanted to show students how molecules move across membranes in a three-dimensional space, and how he wanted to have more flexibility to change the molecule behavior. A 3-D simulation could provide this flexibility.

Gredler (1994) thinks that process computer simulations are suited to representing phenomena that are unobservable or not appropriate for experimentation in the classroom, where symbols can be used to represent interactions that are hard to observe in nature. Simulations for learning physics, for example, have provided students with a degree of control not available in the real world. In the real world students can simply observe two objects falling. A simulation, however, allows students to slow down or speed up the time frame to see events more clearly (Peña & Alessi, 1999).

The physics department at MIT introduced an innovative program that supports the use of visualization and animation to engage their students given that their introductory courses lacked hands-on laboratories. Belcher (2001) explains that electromagnetism has always been a difficult subject for beginning students, and how his course on electricity and magnetism introduces a series of innovative resources that rely on the visualization and simulation of electromagnetic fields and forces. In discussing the advantages of using visualization resources he stated:

> Visualization, especially animations, allows the student to gain insight into the way in which fields transmit forces, by watching how the motions of material objects evolve in time in response to those forces. Such animations allow the student to make intuitive connections between forces transmitted by electromagnetic fields and forces transmitted by more prosaic means, e.g. by rubber bands and strings. (p. 61)

As for the complexity of scientific phenomena, simulations might serve as an efficient tool to provoke thinking and understanding of the behavior of nature. Trying to make sense of how molecules work, or to observe light at the electromagnetic level is very difficult, but the computer can act as a "brain augmenter" (Aukstakalnis & Blatner, 1992, p. 16) and facilitate the visualization of these phenomena.

Experiential simulations have also proven to be a useful alternative for learning. In an interpretive study on the use of simulations for the preparation of school administrators, Mappin (1996) shows that students and instructors found useful associations between their academic knowledge and professional practice situations. Students felt that their experience with the multiple situations encountered in the simulated environment linked with their everyday work activities and really helped them to integrate their previous theoretical knowledge.

Strengths and weaknesses of simulations have been widely discussed (Gredler, 2004; Smith, 1999; Geban, Askar & Ozkan, 1992). The strengths of simulations are mentioned by Norrie (1997), who believes one of the most important advantages of simulations is their flexibility, which allows students to explore them in a convenient time at their own pace. Operational costs are likely to be less when simulations are developed for school laboratories where students may be endangered using real equipment. Nevertheless, he acknowledged that simulations might never match the use of real equipment on the teaching of skills. Concerns about students' sense of engagement and collaborative work when using simulations were also mentioned.

Gredler (1994) supports the use of simulations in education because she believes they could offer a dynamic, more visually attractive, and interactive way to learn. She states that access to more powerful computer systems will ignite the design and development of less time consuming and more cost-effective simulations.

Virtual Reality

It was probably the desire to simulate and visually manipulate events and environments in the computer that quickened the development of more sophisticated software to create virtual reality. Aside from its close relationship with computer graphics and simulations, virtual reality has built its own world. Either as a selective group of high-end technologies and gadgets or as a computerized environment where the imagination has no limits, virtual reality has a tremendous impact in our society. Even when we may not notice this on a day-to-day basis, it has made it possible for us to visualize ideas, knowledge (for example science, arts, fantasy and science fiction), and all sorts of information, making all these available for us to explore, manipulate and interact in ways that would not be possible in the physical world.

The most common name for this technology and its applications is virtual reality, but has also been named: virtual world, virtual environment, artificial reality, high fidelity simulation, and virtual reality environment (Neale, Brown, Cobb, & Wilson, 1999; Moreno & Mayer, 2002; Aukstakalnis & Blatner, 1992).

Given that virtual reality is still a novel technology, its definition has changed continually, and many agree virtual reality is still defining itself as the underlying computer technology improves. The strict definition and application boundaries of virtual reality are also a complex issue because some technologists define virtual reality based on the use of high-end hardware and software (Isdale, 1998), while others define it for its ability to give the user a feeling of immersion (McLellan, 1996).

Lanier (2003) was the computer scientist who coined the term "Virtual Reality." He defined this technology this way:

> We are speaking about a technology that uses computerized clothing to synthesize shared reality. It recreates our relationship with the physical world in a new plane, no more, no less. It doesn't affect the subjective world; it doesn't have anything to do directly with what's going on inside your brain. It only has to do with what your sense organs perceive... (p. 1)

Virtual Reality, and its Levels of Immersion

So, how immersive should virtual reality be? Debate on this issue has varied as much as its definition. While some technologists consider that the purpose and goal for a virtual reality system is to provide a fully multi-sensory interactive experience that allows the user to be effectively immersed by the environment (Brooks, 1999), others consider that the idea of perception of immersion is sufficient for this technology to facilitate its innovative way of communicating information (McLellan, 1996).

In describing a fully immersive virtual reality system Rheingold (1991) explains how:

> Virtual Reality is also a simulator, but instead of looking at a flat, two-dimensional screen and operating a joystick, the person who experiences VR is surrounded by a three-dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it. (p. 17)

Recently, the increased popularity of virtual reality has caused an avalanche of models and categories that contemplate this technology in a broader way (Steuer, 1993). The rationale behind so many different categories and models is its novelty. Fortunately, these categorizations have made room for different types of virtual realities, distinguished by their user interface, level of immersion, user experience, and visual complexity. McLellan (1996) provides a number of models and categories that serve as a reference in distinguishing one virtual reality technology from another and the complexity behind their definitions:

1. By the level of immersion. Jacobson (cited in McLellan, 1996) suggests four types of virtual realities: (1) immersive virtual reality, (2) desktop virtual reality (i.e., low cost home-brew virtual reality), (3) projection virtual reality, and (4) simulation virtual reality.

2. By its relation to the real world. Thurman and Mattoon (cited in McLellan, 1996) developed a different model to categorize virtual reality based on "dimensions," where a "verity dimension" is the level of closeness between the application and the physical world. The two end points of this “verity dimension” (physical and abstract), determine the virtual environment as very close, or very far from the real world.

3. By the user’s interaction with the device. Brill (cited in McLellan, 1996) classifies virtual reality in seven types: (1) immersive first-person, (2) through the window, (3) mirror world, (4) Waldo world, (5) chamber world, (6) cab simulator environment, and (7) cyberspace.

VR Hardware and Applications

Aside from what many interpret as virtual reality, this concept is linked to various technological devices that range from personal desktop computers to specialized computer systems with multiple projection displays. The more technology is added to the system, the more complex it becomes, and the more it costs. Isdale (1998) mentions five levels of hardware systems:

1. Entry VR (EVR), mainly composed by a desktop computer, one display, 2-D mouse, trackball or joystick.

2. Basic VR (BVR), which allows basic interaction with a stereographic viewer (LCD Shutter glasses) and a control device (DataGlove, 3D mouse).

3. Advanced VR (AVR), also based on a desktop computer, but the system requires advanced rendering systems to improve the quality of graphics and frame processing for better real time interaction. Mono, stereo or true 3-D audio output is an important part in this level.

4. Immersion VR (IVR), is a high-end system formed with diverse technologies like a Head Mounted Display (HMD) or multiple large projection display configured with stereo, rear-projected graphics (3 walls and the floor) that form a cave like environment. Some systems may have some form of tactile feedback interaction to increase the feeling of immersion.

5. SIMNET, Simulation for Ground and Air Battle Training. This is an advance system funded by the USA Defense Department that has several virtual reality environments linked together through a network. Soldiers are taught how to work as a team through networked VR tank or jet environments under simulated battle conditions. Other military institutions around the world are also interested in this level of immersion that allows synchronized training in different sites around the world. This virtual reality system has provided a logistically efficient and cost-effective solution in comparison with previous face-to-face training practices.

Today, the application of virtual reality technologies is vast. It is widely used for data, and architectural visualization, for designing, and modeling, and for interior and industrial design. Architects, engineers, and designers have economic reasons for previewing the look and feel of buildings, spacecraft, or machines before production. Airline companies believe that spending on expensive virtual reality equipment is still far less expensive and safer than risking lives by using real airplanes to train their pilots.

Brooks (1999) investigated the kinds of activities and applications that use virtual reality technology. He found virtual reality being used in: (a) Vehicle simulation (e.g. flight simulators, merchant ship simulators, and car simulators); (b) entertainment (e.g. virtual sets, virtual rides); (c) vehicle design (e.g. ergonomics, styling, and engineering); (d) architectural design, and spatial arrangement (e.g. submarines, deep-sea oil platforms, and process plants); (e) training (e.g. NASA); (f) medicine (e.g. psychiatric treatment); and (g) probe microscopy. He also reported that many virtual reality technologies are still in pilot production in the hands of the technologists and researchers. Few have real users doing real work.

Virtual Reality in Education

In the educational realm most of the research that is focused on the educational value of virtual reality has used desktop virtual reality because it is more affordable and more feasible from a production point of view (Bricken & Byrne, 1993, McLellan, 1996; Shim, Park, Kim, Kim, Park & Ryu, 2003).

Academics who support virtual reality technology and any of its categories claim that it possesses certain capabilities (augmentation, simplification, etc.) that could be used to complement learning, and to facilitate understanding of topics that may be hard to explain in a normal learning environment such as the classroom and laboratory. Johnson, Moher, Cho, Lin, Haas, and Kim (2002) pointed out how virtual reality facilitates access to environments that are not accessible:

> Using a virtual world to teach scientific investigation can be beneficial in preparing elementary school students for doing these sort of investigations in the real world .... More importantly, a teacher can simplify the complexity of the world to focus on particular features. (p.6)

Pereira and Hack (1999) speculate that virtual reality presents a different way of seeing and experiencing information. A virtual world may represent the real world in an elementary, symbolic, and artificial way, and it may not be a perfect copy of the environment, but this representation can be used as an advantage for learning. Winn (1993) describes three knowledge-based attributes found in virtual reality: size, transduction, and reification. The size attribute means that we can get as close or as far as we want from a virtual object without losing the notion of sight. The transduction attribute refers to the hardware that serves as a way of communicating between the participants and the virtual software. Finally, the third attribute, reification, is the process of creating perceptible representations of objects that have no physical forms, facilitating the learning experience.

In a pilot study at a summer computer camp Bricken and Byrne (1993) investigated if students would be motivated to use virtual reality given access to this new technology. Students from 10-15 years old were divided in groups and were introduced to virtual reality technology. After being given instructions on 3-D modeling techniques and principles they were encouraged to create their own virtual world, and to design objects to be later integrated in it. They found that students really enjoyed the experience, and were highly motivated to learn how to build their own virtual world. Surveys indicated that students' creativity and imagination were stimulated by the experience. Boys and girls were equally successful in creating elements for their worlds, only female students were more interested in the process of designing and building their virtual world, whereas the males were more interested in completing the task. Collaboration between students was very positive, resulting in strong group bonding.

Virtual reality has shown very positive results in studies focused on special needs children. Neale, Brown, Cobb, and Wilson (1999) believe that virtual reality offers many advantages. They argue that these environments could provide a teaching medium ideally suited for special needs students because the variety of experiences offered by a virtual world might not be available in the classroom. The goal is not to replace real-world experiences, but to fill in with educational 'experience gaps' caused by mobility problems and cognitive deficits. They point out that the ability to learn depends on the range and complexity of the experiences offered to these students, and they strongly believe that virtual reality can provide them with richer learning experiences, given the students' characteristics.

Passig and Eden (2003) used a virtual reality environment to improve structural inductive and flexible thinking processes with deaf and hard-of-hearing children. The study was conducted assuming that these special needs students possess intellectual potential equal to other students, but traditional educational tools are not adequate and do not motivate learning. The study revealed that the experimental group of hearing impaired students that played with a 3-D Tetris game achieved the same level of inductive and flexible thinking as the hearing students (control group 2), while scores of the second group of hearing impaired students (control group 1) that played with a non-virtual 2-D Tetris game remained low.

Virtual reality also proved to be promising in the diagnosis of attention deficit disorders. Rizzo, Bowerly, Shahabi, Buckwalter, Klimchuk and Mitura (2004) assessed child attention performance in a clinical trial that compared eight diagnosed ADHD males with ten non-diagnosed children. Using a virtual classroom environment, visual and auditory distracters were presented in an orderly manner. To capture hyperactivity through the body movements, position trackers were placed on the child's head, arms and legs. Results suggested that the virtual environment could be a more efficient tool for assessing attention disorders since this is such a hard condition to diagnose with the traditional methods available.

The use and implementation of virtual reality is far more complex than the use of 3-D graphics, and is affected by economic, accessibility and health and safety factors. Economic and accessibility factors are the most common factors because any virtual reality experience requires technology that ranges from a desktop computer to very expensive high-end peripherals, depending on the level of immersion wanted.

In the case of fully immersive environments and training simulators, health and safety factors are very important since they have a direct impact on the user's experience. Virtual Reality researchers have found that users have experienced VR-induced sickness, simulation sickness or cybersickness (Lin, Abi-Rached and Lahav, 2004; Sparto, Whitney, Hodges, Furman, & Redfern, 2004; Mollenhauer, 2004; LaViola, 2000), which, according to Lin et al. (2004), is thought to be the result of conflicting motion and orientation cues from the visual and vestibular receptors.

LaViola (2000) explains that users suffering from cybersickness present symptoms similar to the ones in motion sickness. The difference is that many times the user is not moving; moving images cause the sensation of self-motion. Arns and Cerney (2005) were studying the relationship between age and incidence of cybersickness among fully immersive environment users; they found contrasting results to Reason and Brand (cited in Arns & Cerney, 2005) who have confirmed that motion sickness is greater between the ages of 2 to 12, and decreases with time. Arns and Cerney (2005) observed that users between 30 to 39 years old were more susceptible to motion sickness than the groups aged 9-11 or 12-14. These researchers believe that cybersickness is an isolated symptom different from motion sickness, and that it needs to be addressed if virtual reality technologies are to be widely used for research, education and entertainment. It is certain that before this technology reaches the classroom, more research will need to take place on best practices, accessibility, and usability.

According to Rose (1995), implementing desktop virtual reality in the school environment is a highly complex process, and involves human, instructional, and environmental factors. He proposed three categories of factors for learning to be considered when using virtual reality technologies: (1)

Instructional factors, that consist of how instruction influences learning outcomes during the students' virtual reality experience; (2) Virtual environment experience factors, that deal with the students' experiences and activities while they are immersed in the virtual world; and (3) External factors, involving students' characteristics and attitudes towards computers, teachers' attitudes, and background in technology, and a series of social, economic, and political variables related to the environment around the schools.

Assessment of the value of virtual reality technologies for educational purposes is still in its early years and requires further study. Still, there is enthusiasm and a general consensus to strive to find educational value and positive results in the use of virtual reality technologies as tools for learning.

Animation for Learning

When it is required, animation plays an important role in a 3-D simulation providing the motion of the elements that gives a computer generated simulation or virtual environment its realism.

Animation can be defined as a sequence of images or frames that change over time to simulate motion. Animation captures our vision because we are required to dedicate our attention to a sequence of changing objects, colors, and backgrounds to follow-up an event.

Suffern (2000) classifies animations in three types: (1) animations that run from start to finish without intervention from the user; (2) animations with interactive features that allow the user to have some kind of control (playback, stop, fast-forward) or to step through different frames within the sequence of the animation; and (3) animations with interactive features that allow the user to control the information in a organized or random sequence, and the pace in which the information is shown.

The use of animation for learning has become very popular and the accessibility of computers has made animation a very attractive alternative. We often use animation to attract students, and to demonstrate something in a different way. The use of animations seems to be an effective tool to demonstrate how objects move and change in nature, to demonstrate the laws of physics, and to show a sequence of steps, or processes (ChanLin 2000; Suffern, 2000). Also the production of animations is more feasible than virtual reality. Despite the increase in the use of animated tools for learning there are mixed opinions about whether animations facilitate learning and, despite the length of time the art of animated graphics has been around, research on its educational value does not have the same timeline (Rieber, 1990; Dahlqvist, 2000; Tversky, Bauer & Betrancourt, 2002).

Rieber (1990) studied the effects of computer animations through a computer-based lesson explaining Newton's laws of motion at an introductory level. He used static graphics, animated graphics, and no graphics to demonstrate the laws, concepts and rules. In a posttest students' learning performance was measured through their use of the application, by their response latency in answering the questions, and by their attitude towards the lesson, computers, and science. The results showed that students with the animated graphics lesson scored significantly higher (M= 57.7%) than the students with the other two lesson (static graphics, and no graphics). It was found also that response latency increased as the questions level of difficulty increased. Positive and very positive attitude responses were obtained in all the lessons treatments. Rieber considers the contribution of animation in the creation of innovative instructional activities to be important, and a step forward in the design future learning environments.

While studying the importance of visualization and animations in WinEcon, a computer assisted learning (CAL) application for economics, Lim (2001) found that teachers and students considered it very useful to see the scenarios, representations and processes changing in a dynamic way. The relationship between the concepts and phenomena of economic variables was easier to understand, although further analysis of the results revealed that in one particular activity, the animated representations led to misconception of an important topic. The researchers believed that such situations are most likely to happen if students are not previously informed about the limitations of the application, and if their learning is not supported by other instructional activities to confirm that WinEcon animated representations are just conceptual anchors. Because the interpretation of any topic is a different experience for each student, it is also important for the instructor to make sure that the knowledge to be gained relates to the curriculum objectives and goals.

Szabo and Pookay (1994) compared animations, graphics, and text to find out if the use of animation resulted in improved learning achievement. They developed three Computer Based Instruction (CBI) lessons where the objective was to test the participant's ability to use a compass to create triangles. The first lesson showed the process of constructing triangles with animated graphics. The second lesson showed only static graphics to explain the same process, and the third had only a text-based explanation. One hundred and forty-seven undergraduate elementary education majors participated in the study. They were randomly assigned to the three instructional lesson treatments. Findings, as predicted by the researchers, demonstrated that participants scored significantly higher with the animated instruction than the other two groups. Attitudes toward the CBI animated lesson were also significant according to a Likert-type scale, designed to measure attitude towards learning of mathematics using CBI.

We have to be careful not to use too much animation because it can become a distractive element taking the students attention from learning. Rieber (1996) investigating how distractive animated graphics would be as cosmetic enhancers in a computer-based instructional application found no differences in students' performance tests. He cautioned instructional designers and academics from using animated graphics on instructional material since he noticed that students were unable to ignore the animated object while doing the tests. This study suggests additional animated elements are not necessary if they do not enhance or facilitate the learning experience. In such cases it is better to refrain from using animation in instructional material.

Many studies have insisted animation should be used for learning content where movement and change are important attributes, that we should explain why we are using animations before their use as learning enhancers, and that this rationale should be perceived and comprehended adequately.

Tversky, Bauer and Betrancourt (2002) in their review of research on animation, noticed that many comparisons between animated graphics and static ones contained non-equivalent information, thus obtaining biased results toward animations. “Animation should, in principle, be effective for expressing processes such as weather patterns or circuits diagrams or the circulatory system or the mechanics of a bicycle pump” (Tversky, et al., 2002). These researchers suggest that to find out the utility and enabling attributes of animated graphics for learning, animations need to be compared against static graphics.

Researchers have given a series of recommendations that encourage instructional designers and academics to use animation when: (a) we are teaching material that requires students to visualize motion and trajectory attributes; (b) we want effectively to cue students' attention to motion and trajectory details contained in the animation (Rieber, 1990); and (c) we need to provide students with tools where they can convey time or motion-based cues to the learning outcome in a single viewing, giving students the opportunity to replay the animation (Szabo & Pookay, 1994).

Others have cautioned against the use of animation because: (a) not all the students have internalized visual strategies as an automatic process (ChanLin, L., 2000); and (b) students may be overloaded with the amount of animated information (Suffern, K.G., 2000).

Although I believe the use of animation can facilitate the understanding of how electrons move or how the earth rotates while it moves around the sun, we should always consider the context in which we intend to use animation.

Summary of the Literature

As has been shown, research on computer graphics and simulations for educational purposes is not very extensive (Rieber & Kini, 1995; Ronen & Eliahu, 2000; Belcher, 2001) but I believe this situation will change as we become more familiar with these media and we understand their attributes to make the most of them.

The innovative features of 3-D graphics are hard to ignore when we see a growing interest in their use as learning tools. Where understanding of spatial information is relevant I believe 3-D graphics are superior to 2-D graphics. Through the manipulation of lights and shadows computer generated objects can take the appearance of objects in the physical world. 3-D graphics also can be customized to fulfill learning requirements. Simulated phenomena can be magnified for better observation and, as with other multimedia, they can be updated, modified or changed as many times as necessary.

Symbolic simulations of processes are important in this study because their main goal is to represent phenomena in the physical world. DiSessa (as cited in Gredler, 1994) has identified three important contributions of process simulations. First, students interact with the simulation at a qualitative level; second, students' fragmented knowledge of phenomena is challenged; and third, process simulations offer in 15 minute activities, what could take a week for students to investigate in the library.

On many occasions the terms simulation and virtual reality are used interchangeably and it is easy to mix them-up because virtual reality integrates simulated environments, events, or processes. The main difference between a simulation and virtual reality would seem to me that the later aims to engage the senses to achieve when possible, a fully immersive experience. Brooks (1999) mentions that some experts in the area of virtual technology do not consider that using a desktop version of virtual reality offers truly immersive experience because its does not block out the real world, it does not represent objects in real size, and does not create the illusion of immersion. Others, however, think desktop virtual reality can make the user feel quite immersed in the environment, and there are many projects in which desktop virtual reality could be considered as an acceptable first person experience with a much lower cost (McLellan, 1996; Briken & Byrne, 1993).

There is a need for a more qualitative and holistic view of the use of 3-D simulations for learning, as well as a need to explore different areas in which 3-D simulations may have use as learning tools. The studies discussed in this literature revealed a growing interest in all areas of education to examine the instructional potential of these technologies. As Jonassen, Howland, Moore, and Marra, (2003) point out

> Technologies should function as intellectual tool kits that enable learners to build more meaningful personal interpretations and representations of the world. These tool kits must support the intellectual functions that are required by a course of study. (p. 11)

It is the opinion of many educators that more emphasis needs to be allocated for research that deals with the use of new technologies for learning because we still do not know for sure to what extent they influence learning (Dahlqvist, 2000). These innovative technologies will continue to capture our attention, and we will probably see more of them in diverse learning environments. Considering these tools for learning will be constantly changing and improving, we need to be paying close attention to best practices of use.

Chapter Three

Research Methodology

> We know the world in different ways, from different stances, and each of the ways in which we know it produces different structures or representations, or, indeed, "realities."
>
> (Bruner, 1986)

As stated in chapter one, in doing a qualitative study I intended to gain some insight into the usefulness of 3-D simulations as tools for learning, taking into account students' perspectives. I wanted to offer the students a rich visual experience, and my assumption was that the interaction with the 3-D simulation would reinforce their previously acquired knowledge on the subject.

The questions that guided me in the development of this study were:

1. What interactions take place when high school students use a 3-D simulation?
2. What are the high school students' impressions after experiencing and exploring the 3-D simulation?
3. What are the students' perceptions of the usefulness of the 3-D simulation and its educational content for learning?

About Qualitative Research

I decided to take a qualitative approach for the following reasons:

1. I support constructivism as a model of inquiry. I believe we form our own impressions of everything that happens around us, and those impressions influence the way we live everyday. We shape our own concept of the world based on our experiences that at the same time are interwoven within time and space.

Guba (1990) explains how "inquiry cannot be value free and reality only exists in the context of a mental framework (construct)." (p. 25)

2. As mentioned in the introduction, I found very few studies on the use of multimedia for learning that were focused on the "how" rather than the "how much" and "how many." Three-dimensional simulations are so new that there is very little research to contradict or to support claims about their usefulness in the classroom. The research I found on simulations, virtual reality and animation have followed a quantitative line of research (Rieber & Kini, 1995; Bricken, & Bryne, 1993; Szabo & Pookay, 1994).

3. Last, but no less important, was my personal interest in learning to do qualitative research. Reading books, articles and understanding the foundations of how qualitative inquiry works does not make me an expert. I was in this case a learner, and as I present this study, I am exposing my own experiences, accomplishments, mistakes, and shortcomings as a qualitative research beginner.

Five important features define qualitative research (Bogdan & Biklen, 2003):

1) Naturalistic setting as source. The researcher is the instrument that takes the time to absorb the surrounding environment and its characteristics. The data gathered are entirely reviewed by the researcher, who is the insightful interpreter and analyst of the data.
2) Descriptive data. The written word and the quotes from the transcribed data are important in revealing what has been found.

3) Process oriented. Qualitative research is more concerned with the "how" events happened than "how many" or "how much."

4) Inductive analysis of data. The researcher builds the study from the bottom up. Meaning develops as the parts collected and analyzed come together to form a whole.

5) Meaning is an essential concern. Qualitative researchers are interested in how participants make sense of their experiences by capturing their perspectives. (p. 27-30)

By doing qualitative research, we become closer to the phenomena in a naturalistic framework; we are exploring and observing their course, becoming part of the environment itself. In qualitative research depth is more important that breadth, and control over the phenomena is more an inconvenience because it limits us from discovering the phenomena as it unfolds.

A more proper description of qualitative research would be:

> Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretative, material practices that make the world visible. These practices transform the world. They turn the world into a series of representations, including field notes, interviews, conversations, photographs, recordings, and memos to the self. At this level, qualitative research involves an interpretative, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make

> sense of, or to interpret, phenomena in terms of the meanings people bring to them. (Denzin & Lincoln, 2000, p. 3)

Many researchers argue that doing qualitative research alone is not enough, that qualitative research needs the support of quantitative methods, to increase credibility (Leydens, Moskal & Pavelich, 2004; Ng & Gunstone, 2003; Soller, 2004). However, I believe the selection of the methodology very much depends on what the researcher wants to discover, and no matter how much validity we are looking for, in the end the findings will involve much more than our need to fit everything in boxes.

> No one set of rules, no matter how good, can allow us to ask all the questions we need to ask. In particular, quantitative concepts are not very useful in dealing with questions of meaning unless we are looking at meaning as a means for getting to verification. (Shank, 2002)

By observing students' interactions with the 3-D simulation, I was not trying to assert that 3-D simulations were the most effective tools for learning. I wanted to find out what participants experienced with the 3-D simulation, hoping to develop some sense of how useful this resource was useful for the participants as a tool for learning.

Design

As mentioned previously it was my participation in the RACOL project in northern Alberta that allowed me to pursue my research in their environment. Through previous informal conversations with one of the teachers, I inquired about the possibilities of inviting students to participate in my study, given school, teacher, and parents' approval.

The experiences of the administrative and academic staff with the RACOL team eased concerns and provided a background for my presence, which also had an impact on my confidence as the researcher.

Participants

The participants in this study were enrolled in a rural public high school located in Northern Alberta. It was impossible for me to build a good rapport with the students before my visit, and I relied heavily on the physics teacher's support in recruiting the participants given the remote location of the school. After I informed the teacher about the qualitative nature of the study, the teacher invited the participants. Five volunteered to participate but only four obtained permission from their parents to take part in the study.

All the participants were from 11th and 12th grade because it was a requirement that participants have previous knowledge of Unit 4: Light, contained in the Physics 20 senior high school curriculum (Alberta Learning, 2003).

Data Collection and Analysis

Collection

I wanted to observe the student's interactions, to talk about their experiences and impressions of the 3-D simulation. To gather all the data I used a variety of methods: 1) A digital camera to capture students' interactions with the 3-D simulations; 2) A tape recorder to record my conversations with the students;

and 3) a journal both physical and electronic, which I tried to use constantly throughout the study as a self-reflecting tool.

To achieve in-depth data gathering, I planned individual sessions of approximately forty-five minutes each, with a 15-minute break between sessions. I was not certain that I was going to be able to take notes during the student/3-D simulation interaction, so all the sessions were video recorded, and the conversations audio taped. At the end of the student/3-D simulation interaction, I conducted a semi-structured interview with each student.

The semi-structured interview was based on the informal conversational interview (Patton, 2002) and on the interview guide (Patton, 2002). I needed the flexibility of the unstructured interview by Fontana and Frey (cited in Patton, 2002) because it allowed me to be flexible and responsive to the participant's differences and to any changes during the sessions. At the same time, I needed to remember the topics that were necessary to cover, and having an interview guide helped me to maintain focus on the issues that were important.

To obtain feedback about my questions, I carried out pilot interviews with colleagues and friends that helped me practice before doing the actual interviews in Northern Alberta.

Analysis

I transcribed all the data gathered with the digital recordings of each student experience. To confirm the veracity of my transcriptions I listened to the recorded tapes, and repeated this process many times until I was sure I did not miss anything.

I analyzed the transcripts line-by-line using thematic analysis. The categories of analysis were not defined before the study; they emerged during the analysis (Ezzy, 2002). I categorized all the meaningful statements, but kept an open mind when I found categories pointing in a different direction, or provided new insights that I did not consider at the beginning of the study. Once the categories were found, I looked for themes that related to my research questions (interactions, impressions, and usefulness).

Ethical Considerations

To make sure that this study was conducted bearing in mind the best interests of the participants I obtained the approval of the Faculty of Education Ethics Review Board (Appendix A).

As mentioned before, the teacher's intervention was essential for this study as he made possible the participation of the students. The teacher handed out the study information packages and consent forms to all the students, and these were signed by their parents. The information package included a description of the purpose of the study, and a list of all the data gathering methods. The consent forms stated that the participant's involvement in the study was voluntary and if they considered it necessary, they were free to withdraw from the study at any moment without any consequences.

The participants were assured of confidentiality. I made sure that no other person would know the real names of the participants and assigned pseudonyms to each of them.

It is important to mention that the use of video cameras was common practice in the school because of the previous presence of the RACOL project research team. While video recording might be expected to cause participants some apprehension, they stated feeling comfortable with the use of video cameras in the classroom when taking classes in the videoconferencing room.

Limitations and Delimitations

A critical limitation for this study was the inability to build a good rapport with the students before the data-gathering day; nevertheless, I did my best to minimize the effects of the situation. I tried not to act in an imposing way, and I made clear my intentions as I told each participant about the study.

Being the designer and developer of the 3-D simulation may have obstructed my ability to be impartial in the impressions I obtained from participants of the functionality and usability of the 3-D simulation. I was not able to ratify my findings with the students using member check techniques because of time constrains.

Another limitation was the small number of participants. Since one of the characteristics of qualitative research is the breadth and depth of the data, I was concerned about not having more participants in the study.

Chapter Four

3-D Simulation Development

At the beginning of this study I knew I required a 3-D simulation to show the participants, I just did not know whether I was going to use an already designed 3-D simulation, or whether I would design and develop one myself. Using somebody else's 3-D simulation would have had its advantages, no design and production time to be considered, and there could be total emotional detachment from its content.

On the other hand, doing the 3-D simulation myself was a very attractive and feasible idea. It would develop my 3-D production skills and I would have the opportunity to put into practice my recently acquired knowledge of instructional technology. Other advantages I foresaw were the ability to ensure that the content of the 3-D simulation was going to be as effective as I thought it could be, and I would learn far more by embracing the process as a whole: the development process and the research.

I was trying to think of a suitable topic, and after some internal discussion, I chose light. I thought the properties of light to be a very interesting subject for my study, but what really motivated me to consider the concept of light was my belief that visualizing this phenomenon in a three dimensional way might facilitate the participant's understanding of light in nature. In addition, while trying to update my own knowledge of the subject, I noticed that many times the properties of light were represented in a very simplistic way. For example, I found many illustrations of reflection and refraction showing a line representing a beam of light, touching another perpendicular line representing a mirror or a surface, and for some reason, the only elements I saw were lines.

The 3-D simulation was required to contain information consistent with what the students had learned in class. To accomplish this I used the Alberta Learning Physics 20 curriculum for senior high school as a development guide which covered, in Unit 4, the properties of light: dispersion, reflection, and refraction, and the wave model of light.

Designing the Content

For the design of the 3-D simulation I searched for information about other applications with three-dimensional features, but the great variety of simulations for learning that I found on the Internet were two-dimensional. I also explored other tools for mathematics and physics, like The Geometer's Sketchpad (Key Curriculum Press, 2005), and other simulations I found in the LearnAlberta learning resources web site (Alberta Learning, 2003).

Designing the 3-D simulation involved many challenges. I sometimes found myself divided between what I wanted to see represented, and what needed to be represented. During the creative process I imagined multiple ideas of how to represent the properties of light. I thought about using rainbows & prisms for diffraction; a beam of light with animated waves on the inside representing the wave model of light; a diagonal cut of the ocean showing a boat and refracted fish to represent refraction, and many, many more. I imagined a 3-D simulation with breathtaking visual effects, and I thought I could make the simulation similar to a movie. Unfortunately it is one thing to have wonderful ideas and another to work on a feasible and realistic project, all this without considering that time and resources were my biggest constraints.

I decided to concentrate on the most important reason for designing the 3-D simulation. I wanted a unique three-dimensional representation of the properties of light that could help students to better associate the phenomena of light visually, and relate to what they had already learned in class. I wanted the 3-D simulation to be attractive, but at the same time I wanted to comply with the curriculum, which for the subject of light included two major concepts:

(1) Geometric objects to explain the nature and behavior of light, demonstrating refraction and reflection.

(2) The wave model of light, to improve an understanding of the behavior of light.

I first worked on designing the environment in which the properties of light were going to be shown, and after putting aside floating prisms, and lakes reflecting mountains, I thought about a 3-D classroom/laboratory for physics. Very simple, but I assumed students might be more interested in looking at the properties of light in a more familiar simulated physics laboratory.

After I set the environment I started looking for experiments dealing with dispersion, refraction and reflection that gave me a better idea of the elements I needed within the environment. I looked at high school books, encyclopedias, and the Internet. The Internet was my best source. For example, I found a two-dimensional wave model of light where the colors that were used to distinguish the electrical field from the magnetic field served me as a guide for coloring the three-dimensional electromagnetic fields on my 3-D representation. I found also a great number of Java-scripted simulations, graphics, animations, diagrams, and pictures, all for physics, and I realized there were very few web sites with three-dimensional resources. The Molecular Expressions web site, which specializes in optics and microscopy (Davidson, Abramowitz, Olympus America Inc., & The Florida State University, 2005), was one of the best. It was very inspiring, and it really helped me to settle my ideas.

Once I had an established idea of what I wanted and the elements I needed, I started with simple sketches and a storyboard. Every designer works at a different pace and has a different style. It has always been easy for me to imagine and create graphic solutions, interfaces, and environment layouts without putting them on paper, which I do not recommend because time passes by, and the ideas are gone. I always carry a little notebook, but this time I made a conscious effort to keep track of everything, I took notes and drew all my ideas, even the most absurd ones. My notebook was there every time my inspirational muse visited me.

Production of the Simulation

For the development of this 3-D simulation, I started working on an SGI station with PC environment, but later I switched to a Macintosh G5. I used Maya 5.0, which a few years ago became available for the Macintosh, and even though I had previous experience with other 3-D applications (Infini-D, Extreme 3D, and 3D studio Max) learning Maya was a completely different experience. Many 3-D software packages have similar features and interfaces, but in the end there is always a steep learning curve. I spent more than three months learning the software.

During the animation of the 3-D simulation, the camera was a very important element; it acted as a physical camera, and provided me a window to see how the participants were going to experience the 3-D simulation. All the elements were created from scratch. I knew there were libraries of 3-D objects but I did not have the resources to buy them, so I built the most important elements, leaving the ones for decorative purposes to the end, in case I had time to spare. Once I had the classroom built I saved it as a master and saved five copies, one for the introduction, and the other four for each phenomenon.

Some sequences were more complicated than others. In the sequence of dispersion I had trouble representing the colors of the rainbow. I tried in the beginning to achieve it with seven different lights, but in the rendering process, the lights dissipated. Probably it was more inexperience than anything else, but I decided to use cylinders with maximum transparency and incandescence to represent the diffracted colors from the white light beam. Another production problem was the mirror in the reflection sequence, because once I built a three-dimensional object I had to assign it a material (the material is what gives the object its characteristics inside the environment) and finding a material that would look like a mirror was a long process of trial and error. This is because I was not really able to see how the objects would look within the environment until the scene was rendered, and the rendering process time depends very much in how much quality I required for the simulation. The software had a frame preview that allowed me to render a specific frame to give me an idea of how the colors, the materials and the lights would look, but since I was animating, I had to render the whole sequence.

All the sequences were rendered in a 640 x 480 resolution. I did not want them bigger because that would involve very long rendering times. There were two sequences that took over two days of rendering time, and sometimes if the sequence did not have the necessary quality, I had to repeat the process. That happened a lot.

The scenes were rendered and exported as QuickTime files. I used After Effects to add the text and to combine the sequences to make a single file that was also exported as a QuickTime movie and burned to a DVD disc.

For the presentation to the research participants I did not compress the files because I knew I would have to take my own equipment. I knew I would not have access to the school computer laboratory, and that any of the software I used would be installed on my own computer. Many school districts have very strict policies in their computer laboratories, and my study was going to take place in one day. I decided then that it was better to show the participants the 3-D simulation with the highest resolution.

Description of the 3-D simulation

At the beginning of the scene the camera captures a high school hall. In the middle of the hall there is a classroom with a blue door. The walls of the school halls are painted with a soft yellow, and the floor with a soft blue.

First Sequence: introduction

The camera zooms towards the blue door. The blue door opens and the camera shows a laboratory classroom (see Figure 3). As the camera slowly enters the classroom, you can see wooden tables, with stools, and equipment cabinets. There is a big table at the centre of the room in front of a whiteboard.

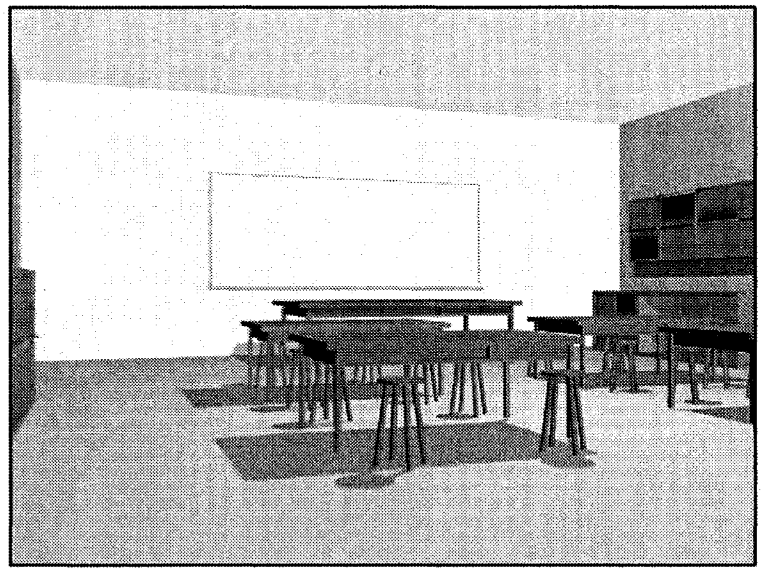

Figure 3. Frame taken from the 3-D simulation (emulation of a physics laboratory)

The room is brightly illuminated, more so than the hall. The camera continues to move towards the end of the classroom laboratory. It passes between the tables, and stops in front of the centre table in front of the whiteboard. After a few seconds a title appears on the whiteboard displaying the text: "3D Simulations for Physics." After a few seconds another title appears displaying the text: "Unit 4: Light" followed by two separated lines: "1) Nature and behavior of light" and "2) Wave model of light." The letters disappear to reveal the next set of text: "1) Nature and behavior of light: a) Dispersion; b) Reflection; c) Refraction."

Second Sequence: dispersion

A title shows on the whiteboard "1) Nature and behavior of light: a) Dispersion." After a few seconds the camera shows the main table from the left side of the classroom. The table has a light box and a glass prism on top. The camera slowly zooms towards the table as it pans and tilts trying to get to the other side of the room behind the main table.

When the camera is closer to the table the light box produces a beam of light. The beam of light then touches the glass prism and the phenomenon of Dispersion occurs as the beam of light passes through the glass generating the colors of the rainbow. The camera pans to allow the phenomenon to be seen from different angles, while maintaining focus on the table (see Figure 4). This scene ends with the camera showing the table, the light box producing a beam of light and the glass prism from the right side of the room almost behind the big table, dispersing the white light into a color spectrum.

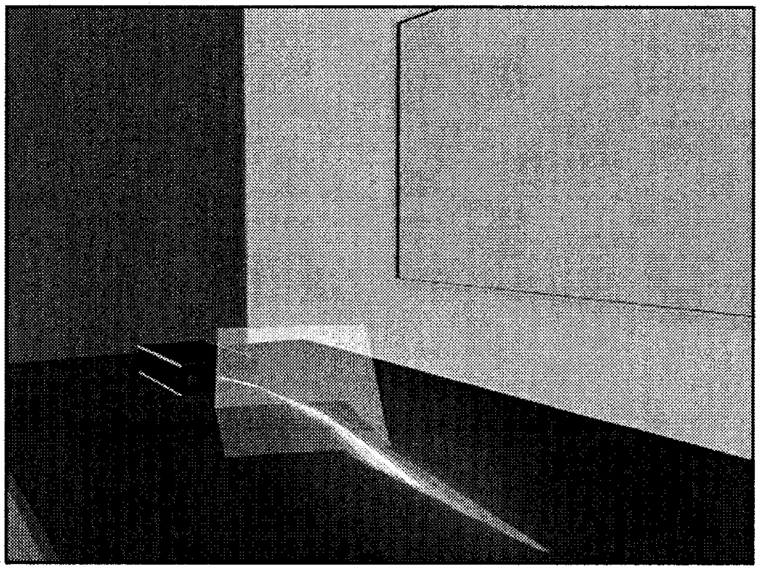

Figure 4. Frame taken from 3-D simulation
(second sequence: dispersion of light)

Third Sequence: reflection

A title appears on the whiteboard at the centre of the laboratory room: "1) Nature and behavior of light: b) Reflection." The camera shows the table from the left side of the classroom, and the light box shows on top of the table. A mirror is positioned perpendicular to the surface of the table. This mirror is shown reflecting the hidden side of the classroom, and as the camera zooms towards the table the light box produces a beam of light and the phenomenon of Reflection occurs (see Figure 5), the beam of light is reflected on the mirror and the camera stops.

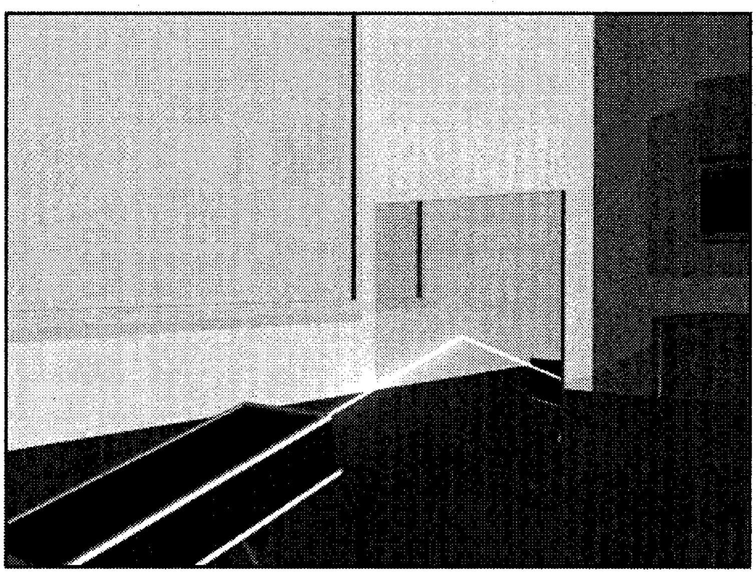

Figure 5. Frame taken from 3-D simulation
(third sequence: reflection of light)

Fourth Sequence: refraction

Text appears on the whiteboard at the centre of the laboratory room: "1) Nature and behavior of light: c) Refraction." The camera shows the main table from the left side of the room. The table has on top a large blue glass container with water with a glass stick inside.

The camera zooms very slowly while the phenomenon of refraction occurs. The stick inside the container looks bent through the glass, an effect that occurs when the light passes through the water (see figure 6). The simulation ends when the camera is aimed directly to the glass container.

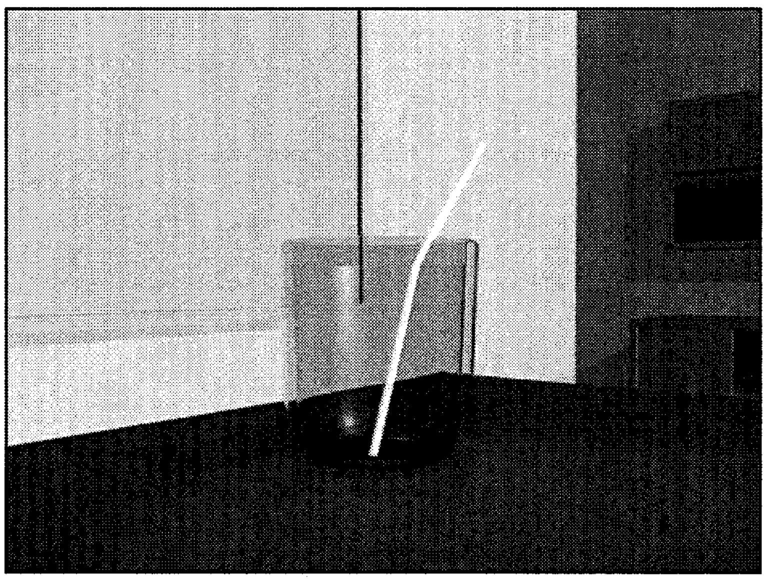

Figure 6. Frame taken from 3-D simulation (fourth sequence: refraction of light)

Fifth Sequence: wave model of light

The camera shows the whiteboard at the centre of the room, and text appears: “2) Wave model of light.” On the far left corner of the screen small text appears: “Light Beam.” The room is dark, and the camera is positioned diagonally close to the main table. The light box is on top of the table. The camera zooms towards the table while the light box produces a beam of light. The camera comes to a halt almost a the edge of the table, and the beam of light is replaced by a series of red halos that are moving in the same trajectory as the beam of light but in cyclical periods; the red halos grow in size as they move. Few seconds after, the beam of light and the red halos are shown at the same time.

In another scene small text appears in the left far corner of the interface: "Electromagnetic Waves." There is a three-dimensional electromagnetic field floating in space (see figure 7). The electrical field is represented in red, and the magnetic field with blue. Each field has a sphere moving through each corresponding color. These spheres move from start to end of the electromagnetic field, and are intended to represent the constant movement of electromagnetic energy.

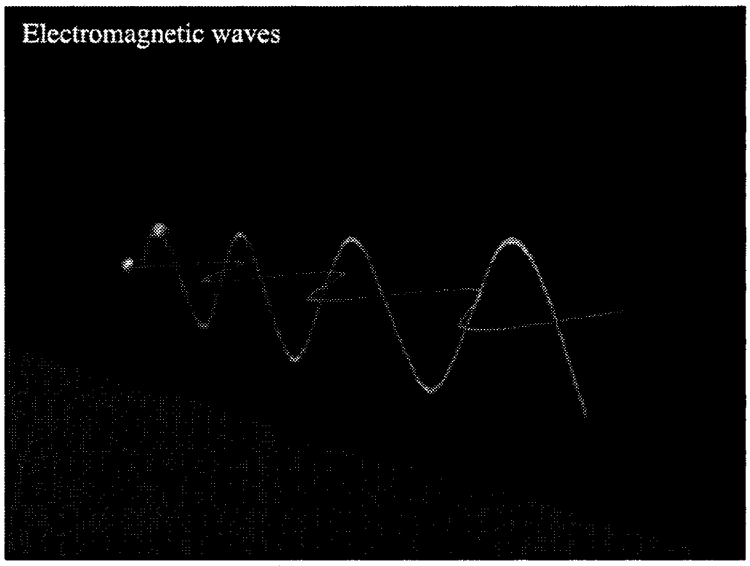

Figure 7. Frame taken from 3-D simulation (electromagnetic waves)

Summary

There were many issues that arose when I embarked in the design and development of the 3-D simulation. Working with Maya was not an easy task. There were many times that my lack of experience and expertise caused me to repeat processes and delayed the production schedule. In fact, the three months I planned for having the 3-D simulation complete became more than six months, and this affected the entire time line of the thesis.

During the design and development process of the 3-D simulation, I was more concerned about the level of accuracy of the concepts than in the production values (not that the production did not have its own challenges). I wanted to represent the properties of light and the wave model of light in a clear and simple way that could help the participants relate to what they had learned before in class.

The 3-D simulation was not designed with any interactive features because of time and budget constrains, but I wanted to give the students some control during the interview sessions. Exporting the simulation as a QuickTime movie facilitated the control the students needed to go back and forward, and to observe the 3-D simulation at their own pace.

In the next chapter I present my findings, along with personal reflections about the participants' interactions with the 3-D simulation and the interviews.

Chapter Five

Findings

> Learners induce, or construct, their own concepts and rules based on their interpretation of the particular cases encountered through experiential learning in a particular domain.
>
> (Mayer, 1983)

My Visit to Northern Alberta

The purpose of this study was to gain some insight into the usefulness of 3-D simulations. I wanted to find out first hand, from the students' perspective, how useful 3-D simulations were as tools for learning.

To report my findings I use a personal narrative style. The style and the interpretation of the events will be influenced by my previous experiences and values, as Bogdan and Biklen (2003) state: "Individuals interpret with the help of others – people from their past, writers, family, television personalities, and persons they meet in settings in which they work and play-but others do not do it for them. Through interaction the individual constructs meaning." (p.33)

Day I

I visited Northern Alberta two days before the day set for the interviews to have at least one day to know the place and the school. It was a long trip and by the time I arrived, it was already dark. I had previously arranged my stay with a local hotel, so I had no problems finding the place. Once I got my room I settled in. I started to take some notes and prepared everything for the next day, which I had planned specifically to visit the school and to talk with the teacher.

Day 2

I drove around the town to find the high school and a place to have breakfast. I found a restaurant just in front of the high school. It was a beautiful sunny day, and the town was quite active. Kids were playing on the streets, and people were walking by. After I had breakfast, I decided to visit the teacher and to look at the classroom that was assigned to me for the interviews.

I entered the school and visited the administrative office to introduce myself, and to find out if I could talk to the teacher. After all the formal introductions I went to see the teacher, who pleasantly informed me that everything was ready. He gave the location of the classroom I was given permission to use, and invited me to look at it.

I walked down the halls and I found it, it was the classroom for fine arts, music and drama, also used regularly for First Aid workshops. It was a very ample room with white walls, well illuminated. It had a window and an emergency door on the far right. There were different groups of objects on each side of the room: stacked chairs on the far right corner; a computer station on the far left; a file cabinet at the end, and right on the left of the classroom door an exercise mat with various objects including First Aid equipment.

Each wall of the classroom had at least one board; I assumed this way students would have the possibility to engage in different activities all across the classroom. From the door's perspective, on the left side of the room there was a long green chalkboard positioned in the middle of the wall, and over it was a white board, displaying a map of Alberta. In front of the whiteboard was a small round table with an opaque objects projector, and to the left of the round table was a rectangular table. I looked at the classroom again, this time thoroughly, trying to find a good and comfortable place for all the interactions to take place. I thought of moving the opaque objects projector and using the small round table. I imagined I would have enough room to set the computer, the camera and the tape recorder.

After having found the right spot I went back to thank the teacher. I left the school and prepared myself for the next day. When I first arrived at the school I was worried and nervous, but after talking to the teacher, and looking at the classroom I felt much better.

Day 3

I arrived at the school a few minutes before the classes started. I got all the equipment and went directly to the classroom. The chairs were already arranged at the end of the room. I set the computer on the table, with the monitor facing the green board. I positioned the digital camera facing the monitor, that way the camera would only capture the students' back, and their faces could not be identified. The tape recorder was placed beside the monitor to be at hand when needed.

I took some time before the interviews with the students to take some notes and to check on my interview guide. I checked the computer to make sure the simulation sequences were in order. I took a big breath and waited for my first participant to arrive.

Adrian

About Adrian

When I interviewed Adrian he was in Grade 12. He wants to go into medicine, and he is very interested in technology. Adrian has a computer at home and he likes to play video games. He enjoys playing 2-D and 3-D games, but he thinks that the new 3-D games were cooler.

Session Events

Adrian entered the classroom and introduced himself in a very polite way. After shaking hands I explained the reason for my visit. I showed him the computer and invited him to sit in front of the monitor. Adrian observed the monitor while I was explaining what the session was about. I explained what he needed to do and immediately he grabbed the mouse and played the 3-D simulation. There was a long silence. He went quietly through all the 3-D simulation sequences, and then he stopped.

After seeing the simulation he took his hands off the computer, and started playing with his fingers. He looked at me when I asked the first question, but kept holding his hands and playing with his fingers. I asked about the 3-D simulations and he stated that it shows the refraction, and "gives you a visual image whereas the textbook just shows straight-line diagrams" (Adrian, Interview).

He turned many times to look at the monitor after looking at me, but after a while, he just put his elbow on the table, grabbed his hair, and looked at me. "I find the sequence on reflection to be a little too fast," he continued looking at the computer monitor, and said "I'm not sure how you add audio" (Adrian, Interview).

When we started talking about other 3-D games, and 3-D simulations his tone of voice increased. He kept holding his hands but he moved a little bit more this time. Adrian said “I like playing games, I like the new ones, but I play the old ones too” (Adrian, Interview).

Reflections

Adrian was not particularly interested in the 3-D simulation; his answers were polite but distant. I observed that after playing the 3-D simulation and going through all the sequences, he never played it again, and he did not touch the mouse again. His hands were closed together over his lap. He would move looking at me, and then at the monitor but that was it.

I tried to ask more questions but I noticed that he looked discreetly at the door; he was particularly quiet. He answered to my questions and comments with a yes, a nod or few hand gestures, but nothing else, our interaction lasted just 8:00 minutes. I thank him for his participation, and let him go. He stood up and left the room.

I was very worried at that moment, and felt disappointed by his attitude. After reflecting on it, I started to reflect on the time constrains of my visit, and the fact that the students’ term was almost over. Maybe he had more important things to attend to, and for a moment I felt powerless. Should I have maintained the conversation for a longer period? Did I need to be more imposing? To have shown more authority? It was a fact that I felt very nervous during the first five minutes. Maybe without noticing I displayed uncertainty.

In the end I realized that any of those factors would have guaranteed a change of attitude. That it was my first session and I should not give up so soon.

Billy

About Billy

Billy is a Grade 11 student. Billy enjoys helping other students to learn, which is why he wants to be a teacher like his brother. He likes social science, and he plans to go to the University of Alberta. He wants to go back home after he is done his bachelor's degree.

Billy likes animated movies like Monsters Inc, and he is used to playing many video games with his brother's videogame system.

Session Events

Billy arrived with the teacher a few minutes after Adrian left. The teacher left, I introduced myself to Billy, explained the reason for my visit, and what I needed him to do. He remained standing up until I asked him to sit down in front of the computer. Once he sat, he rested in hands on his lap and played with his fingers while I was preparing the 3-D simulation.

He grabbed the mouse and started playing the sequences of the 3-D simulation one by one. I saw him looking attentively at the monitor, and holding the mouse even when the simulation was running automatically. He listened to my instructions and followed them.

He played all of the 3-D simulation sequences, repeating the sequences four times. Sometimes he would stop and look at a specific sequence. While we were talking about his experience with 3-D simulations he clicked on all the sequences and looked at them all again at a fast pace. "We had some simulations before in video conferencing, but none quite this good. They were just flat; it would've been nice to have something like this" (Billy, Interview). While he was answering, he did not let go of the mouse. "The sequence on refraction seems slow" (Billy, Interview).

Many times I noticed that his attention was divided between looking at the simulation and listening to me. When I asked if he understood the content he said "Yes, I think that I've gone through the course. I know what this is" (Billy, Interview).

He spent a long time looking at the wave model of light (WML), grabbing the mouse, and moving the cursor around that specific sequence. When he wanted to state something he would move his hands and finders doing circles and touching the monitor to be more specific. "I think the graphics were really good in the last one (WML) and the effects, or what you did, but maybe it needs more information in the bottom or something" (Billy, Interview).

We were talking about 3-D and he mentioned:

> I think it helps; I like to see it in three dimensions than just talking about it or seeing on the textbook. It helps you see how it is in three dimensions, especially with the videoconferencing program we have here, where you don't do any experiments with the teacher. He can't really show you how it is reflected or refracted or whatever, so this could be very nice. (Billy, Interview)

I asked if his understanding of the topic would be complete having already knowledge of the subject, and seeing the 3-D simulation. "Oh yeah, for sure. If they took Light in class they would know what is going on, and then they see this, it can help them to complete their understanding instead of just partially" (Billy, Interview).

Billy was looking at the wave model of light when I asked if he had previous experience using other simulations.

> Well we had one that was kind of 3D, it wasn't that advanced as this, complex as this. It helped one student in our class to learn it all better, and to understand it more. This one shows it better, because there is more, looks like there is more time put into it. (Billy, Interview)

While he was observing the sequence on Dispersion he touched the screen and said:

> See, for this one here I thought was actually really good because you can see the incident beam as it bends, and it changes into different colors, and then bends again; there is an even wider aspect in all the colors and I haven't really seeing it quite like that before. Like I knew it but I hadn't seen it like that. I thought that one was really good. (Billy, Interview)

While he was explaining how the beam of light dispersed into the colors of the rainbow, Billy touched the rainbow while the 3-D environment camera was panning around the prism.

When he was looking at the sequence on refraction I talked about the 3-D simulations based on the properties of light, and the use of visual tools for learning, he said:

> I am a very visual learner, too, and then if someone is just explaining something I'll be thinking of some explanation in my head or whatever; try to visualize it more, and I have gotten quite good at that over the years, but some of my friends still struggle with that, so explained like this would really help them. Like with the more visual aspect of it, showing how it works, and especially for videoconferencing. They don't do experiments at all; I think it is because the teacher's so far away. Something like this could really help them. (Billy, Interview)

He kept playing all the sequences without order, listening to me, but moving the cursor on the monitor with the mouse.

In the last ten minutes of the interview he listened attentively to my questions, and my comments; after that he grabbed the mouse again and looked at the 3-D simulations again, selecting all the sequences and talking about his expectations for 3-D in the future.

Reflections

I believe the fact that Billy wants to become a teacher prompted him to approach the questions in a very specific manner, as if it was not only important to him but to his peers too. I noticed in his answers that many times he placed himself in the position of the teacher, or in the position of his classmates, trying explaining how hard it is for students to learn something when they do not understand the topic.

Billy was very participative, and made many suggestions for the 3-D simulation sequences to look better. He suggested different scenarios and different content while he was constantly touching the screen and indicating with his hand gestures where the changes should go.

Billy's interaction with the 3-D simulation was a relief, not only because I knew I would find some answers but because he was very enthusiastic, and I do not think he was being dishonest. He seemed to be enjoying himself, asking questions, moving his fingers, touching the 3-D simulation, and observing with detail all the sequences. Considering my previous experience with Adrian, I was concerned that the other participants' attitudes would be similar but I was mistaken, Billy's interest and active interaction with the 3-D simulation allowed for a good conversation on its features. The interview with Billy helped me regain my confidence, and to feel less stressed, which I think facilitated our interaction.

Colin

About Colin

Colin is a Grade 11 student. He wants to be a power engineer. He likes designing and building things. He likes physics, and understands physics with ease. He has a computer at home and likes to play computer games. He likes games because he could change the outcome, and he really liked 3-D because he could feel the environment.

Session Events

Colin entered the room with a big smile and gave me an enthusiastic handshake. He sat on the stool immediately without me asking him. While I was changing the tapes, and setting the video camera he observed me attentively and asked about my trip. We had a pleasant chat about roads and weather.

I set up the 3-D simulation and explained to Colin what he needed to do, and talked to him about my interest in his experience and why I needed his impressions of the simulation. He grabbed the mouse and played the 3-D simulation quietly for about three minutes. With his hand on the mouse he played the simulation two times more. When I asked about his experience with other simulations he said "not in physics though, we used to have some on the computer for basic physics like observation of momentum and stuff like that but not anything like this" (Colin, Interview). He kept his hand on the mouse during the time he was interacting with the computer.

He finished looking at the sequence on reflection and I asked if he visualized it better, he mentioned "Most definitely, when you watch the movie it makes way more sense than what they try to tell you in the book. Like you can see the light splitting or diffracting or whatever" (Colin, Interview).

When I asked Colin his impressions of the usefulness of the 3-D simulation and if he understood the subject he said, "It's kind of hard to say, because the properties of light was about the easiest topics I caught on to in physics 30. I kind of understood it already" (Colin, Interview).

We asked him what he thought about the 3-D simulation features he mentioned phrases like "it's way better" (Colin, Interview) and "this I can watch, and probably watch it to the end. Well if it's the text book, you read the first paragraph and it's like close the book and go to sleep" (Colin, Interview).

I asked him his impressions of the simulations being done in 3-D: 'It's got it, I can't imagine anything being able to be better than 3D, well, other than virtual reality. That would be I guess the ultimate application but think that's kind of impossible" (Colin, Interview).

He played the 3-D simulations many times, clicking at the different sequences in no specific order. He suggested adding interactivity to the 3-D simulation and finally he stated

> I have to say my understanding at least of physics was pretty much the same level, so it didn't really make that much of a difference to me, but somebody who doesn't understand it along with the textbook, it probably be able to understand it a lot better. (Colin, Interview)

Reflections

Colin was very outgoing and seemed very attentive and participative during the interview, looking at the monitor and observing the 3-D simulation sequences repeatedly. He seldom rested his hands on his lap. He was very expressive with his hands when he wanted to show me something, or while answering my questions.

I noticed that he had a very good idea of the concept in the 3-D simulation and I do not know if seeing the 3-D simulation changed his previous understanding of the subject. He did acknowledge the 3-D simulation was attractive and had innovative features, he talked about its possible potential, as a way of saying that if he had not understood the subject in class, he would have understood using with the 3-D simulation.

I was satisfied with Colin's input. He seemed very honest. He did like the 3-D simulation but at the same time he felt he had already understood the properties of light, so he was impartial towards its use in the classroom, for this particular situation.

Don

About Don

Don is a Grade 12 student. He wants to go to the university but he does not know if he will have the monetary resources to do so. He did not mention what he wants to study, but I assume it has to do with technology because he mentioned that he likes virtual environments and programming, and he wants to learn to create 3-D animations, and games. Don does not have a computer at home but he likes 3-D games nonetheless.

Session Events

Don was my last participant. He arrived and sat in front of the monitor. I explained to him why I was visiting the school. He looked attentively at the monitor without touching the mouse. I talked to him about what he was required to do, and only then did he hold the mouse and play the 3-D simulation.

Don observed the 3-D simulation sequences and he started suggesting things while going through each sequence. He seemed very interested, and looked at the same sequence many times. He said: “It’s not bad. It needs some sort of narrator” (Don, Interview). I asked why he thought it was not bad, he replied, “because you can see more dimensions, a better visual image of it” (Don, Interview).

I noticed that he was very interested in the wave model of light sequence. He played it many times. After looking at that sequence for a moment he played the first introductory sequence, and he said “A familiar environment, that’s cool” (Don, Interview). He touched the screen and as he pointed at the stools and the tables he said, “There is more of a classroom situation. Like a real world application” but after that he started suggesting more elements to be integrated in the 3-D simulation “with something like a window and having the light coming and refracting like that” (Don, Interview).

Reflections

My session with Don was a very interesting one. For a moment I thought “maybe he misunderstood me and he thinks he has to evaluate the 3-D simulation” because in every sequence he kept suggesting changes. He would distance himself from the monitor to get a better look and then he would get close again to grab the mouse. He asked questions while pointing at the sequences with his finger that many times touched the monitor. He used his hands actively while making comments.

On many occasions I noticed that Don got distracted with other aspects of the 3-D simulation and would not answer the questions. This was of course caused by my lack of experience because I felt that I lost control of the interview. I did not feel the same way with the other participants. Don's interest was obvious, but now that I have given it some thought, maybe he was more interested in the innovative features of the 3-D simulation than in its usefulness as a tool for learning.

While looking at the wave model of light, Don touched the screen from point to point trying to follow the animation of the model, as if approving the sequence. He seemed most excited about the 3-D simulation; he spent a lot of time going through all the sequences. In my personal point of view he was the most enthusiastic about the 3-D simulation.

At the end, he kept sitting in the stool, as he did not want to go. Finally the teacher came into the classroom to fetch him. I did not know whether the fact that he did not have a computer was a factor. He asked me many questions about the computer, and the programs that I used to produce the 3-D simulation.

Chapter Six

Discussion and Summary of the Study

Answers to Research Questions

As stated in the introduction, the purpose of my study was to gain insight into the usefulness of 3-D simulations. I wanted to find out first hand, from the students' perspective, how useful 3-D simulations were as tools for learning.

What interactions take place when high school students use the 3-D simulation?

When I found out that I had been given permission to do my research in Northern Alberta I was excited, but I was concerned that my inability to build an adequate rapport with the participants would have negative effects on my research. I was worried about the participants' reaction to the study and my presence in their environment. My preconceptions about teenagers' unpredictable attitudes made me expect an apathetic response. I was wrong.

The participants were polite and attentive during the interaction/interview sessions. However, while I was analyzing the data I questioned whether the interactions with the 3-D simulation and their answers to my questions derived from their sense of politeness and not from their true interest in the 3-D simulation as a tool for learning.

All the participants used the 3-D simulation successfully, and seemed comfortable with the use of the computer. Billy, Colin and Don showed interest, asked questions and made suggestions about how it could be better or cover more content. Unfortunately, Adrian's interview was so short that it was not possible to draw much from it.

What are the high school students' impressions after experiencing and exploring the 3-D simulation?

The participants seemed to appreciate the visual features of the 3-D simulation, and the data strongly suggested their interest in the use of 3-D simulations as a complementary tool for learning the properties of light. Gelband et al. (1998) indicate that adding 3-D features offers a richer learning experience, including increased engagement, development of spatial skills, and a natural and more intuitive interface.

When I asked the participants to tell me about their impressions of the 3-D features of the simulation, all the students made similar statements: "[the 3-D simulation] gives you a visual image whereas the textbook just shows straight-line diagrams" (Adrian Interview), or "[the 3-D simulation] it's way better" (Colin, Interview), and "this [3-D simulation] I can watch, and probably watch it to the end. Well if it's the text book, you read the first paragraph and it's like close the book and go to sleep" (Colin, Interview).

What are the students' perceptions of the usefulness of the 3-D simulation and its educational content for learning?

How useful was the 3-D simulation? The answers were divided. While two of the students found it very useful, the other two stated they had already learned the subject, and the 3-D simulation was not necessary. Nevertheless, all of the participants agreed that if they had not understood the subject they would appreciate the 3-D simulation. Two participants commented that their classmates would really benefit from using the 3-D simulation during or after class, because they had problems understanding the topic.

The participants also considered themselves visual learners. This was particularly interesting because I never mentioned learning styles. With comments like: "I'm a visual learner, and if somebody is just explaining something I'll be thinking of some explanation..." or "I'm a visual learner, I don't get books" (Colin, Interview), I assumed they knew the concept and understood better using visual tools.

The 3-D simulation

When I designed this study, I knew I did not possess enough experience to design an interactive 3-D simulation on the properties of light, such an endeavor would have required more resources and more production time. However, I was determined to do my best by building a good simulation for learning, and one which was made more dynamic by animating the camera. I followed some of the recommendations I found in the literature on the use of animation when: (a) we are teaching material that requires students to visualize motion and trajectory attributes; (b) we want effectively to cue students' attention to motion and trajectory details contained in the animation (Rieber, 1990); and (c) we need to provide students with tools where they can convey time or motion-based cues to the learning outcome in a single viewing, giving students the opportunity to replay the animation (Szabo & Pookay,1996).

Computer graphics still require efficient and powerful computer systems, especially when developing 3-D simulations. The more complex the product, the more computer capacity is necessary. I was amazed by the large amount of processing time it took the computer to render the simplest detail. I imagine that in the corporate world the efficient use of production time would be extremely important.

The experience of designing and developing the 3-D simulation was very exciting, but as mentioned previously, more research oriented to this tool and its development for educational environments would have been helpful.

What was learned from the Study

When I designed the study I assumed many things. I assumed that the participants would like the 3-D simulation, and that the 3-D simulation would facilitate their understanding in the topic. My first assumption was confirmed, the participants did like the 3-D simulation and showed great interest in it. However, the second assumption remains in question because their descriptions of its usefulness were not extensive enough to help me interpret how the simulation affected their understanding of the properties of light.

My experience in graphic design was not enough to prepare me for a journey such as this research project, in which rather than considering the needs of the corporate client, it was necessary to consider the need of the student. Such needs, I believe, involve more responsibility.

Another challenge was to write in English. I am a native Spanish speaker and many times I found myself thinking of good ideas that as soon as I got in front of the monitor I just could not express in English. Nevertheless writing this document has been a fruitful experience, I have learned far more than I expected, and it is indeed, no matter how small, a big accomplishment for me.

Recommendations for Future Research

The literature on the use of 3-D simulations as tools for learning is still very limited. Most of the research I found was oriented toward 3-D graphics potential applications (House, 1996); few studies have investigated the use of 3-D simulations as tools for learning (Gelband et al., 1998; Garg et al., 1999; Schonhage et al., 2000; Suffern, 2000). This situation suggests that further research is necessary to understand how 3-D graphics may be used in educational environments.

Rieber (2000) mentions the reasons why he did not cover three-dimensional graphics and virtual reality in his most recent book:

> First, most of these areas have not, as yet, been sufficiently applied to educational settings. For example, computer visualization has been applied most frequently in fields such as architecture, medicine, art, and commercial television. Second, few of these areas have migrated to desktop computer applications. As educational practice catches up to the potentials of computer graphics technology, this will surely change. (p.275)

I believe that 3-D simulations will be an essential part of all the new technologies for learning (multimedia, games, virtual reality, etc.), but further multidisciplinary research is necessary to fully understand how these tools facilitate learning.

The findings of my research were limited to the environment in which the study took place, and many questions arose after the study was completed:

1. What about female interactions with the 3-D simulations? I did not have a chance to inquire into female participant's impressions because all the participants who volunteered for the study were male. I believe an equal participation of female and male participants may have provided more diverse findings.
2. The 3-D simulation covered the properties of light, a small fraction of the physics curriculum. A more complete set of 3-D simulations covering diverse topics and longer interactions with students might provide with more depth and understanding than my small study was able to capture.
3. The duration of the simulation was too short. Would participants experiences be richer if the 3-D simulation lasted longer?
4. Would an interactive 3-D simulation be more adequate than my 3-D simulation to facilitate learning of the properties of light, and other scientific phenomena? A 3-D simulation with interactive capabilities would be more expensive but I think further research could determine whether increased levels of interaction facilitate the students' understanding of the subject.

Conclusions

Doing qualitative research was a most gratifying experience as my experiences, conceptions, and constructions of the world made me approach this research in a unique way. I hope this study contributes to the growing research into new technologies for learning through qualitative methodologies.

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Appendix A

Letter of Consent and Information Package

RACOL
Rural Advanced Community of Learners

RESEARCH THESIS INFORMATION PACKAGE

Use of 3D Simulations for Learning Physics, an Interpretative Study

Purpose of the study
Despite the increase of applications for learning with 3-Dimensional features (simulations and games) there are many questions to whether these resources possess any value for learning.

With the fast advance of personal computer systems, the design and development of 3-D simulations is becoming more and more common. At the same time the use of these resources has also become available for teaching and training. Lately there has been an increase in the use of simulations and visualization applications for teaching science, especially physics.

As a researcher I am deeply interested in the future development of learning resources using 3-Dimensional features. This interest encouraged me to create and develop a pilot 3-D simulation with the belief that this resource could help students to understand the properties of light (dispersion, reflection and refraction) and the wave model of light.

Study Goals
To acquire a better understanding of how students learn through the use of 3-D simulations.
To gather information about the students' previous experience using 3-D simulations as a visualization aid.
To listen to the students' perceptions, opinions, feelings, and understanding of the topic represented in a 3-Dimensional way.
To obtain the students' input for the future development and improvement of the 3-D simulation.

Information Gathering
To gather the necessary information for my study, I will use these methods:

1) Tape recorded personalized interviews
2) Observations which may include field notes
3) Video recordings of the participants

Confidentiality
Consent Forms have been developed for the purpose of obtaining consent from those

RACOL
Rural Advanced Community of Learners

CHILD PARTICIPANT CONSENT FORM

Note: There are two purposes for this consent form, 1) to acquire consent regarding in-person research activities and 2) to acquire consent regarding the tape and video recording of your son or daughter during the study, and possible use of these tape and video recordings to acquire the necessary information that could help the investigator to conclude this research study.

I acknowledge that the study procedures have been explained to me, and that any questions I have asked have been answered to my satisfaction. In addition, I know that I may contact the researcher if I have further questions either now or in the future.

I have been assured that personal records relating to this study will be kept anonymous. I understand that my child is free to withdraw from the study at any time and will not be asked to provide any explanation.

Please initial the appropriate boxes below to indicate your willingness to grant permission for your son or daughter, ____________________, to participate in this study.

Research:

______ I consent to allow my child to participate in this study by being interviewed.

Use of video recordings
Although no harmful consequences are anticipated from the participation of this study, we require to asking you to agree to the following disclaimer.

______ I consent to allow my child's video recorded image and voice while participating in this study.

Please finalize your consent by completing the items below. Thank you

____
(Date)

____
(Name of Child) please print

___________________________________ ___________________________________
(Name of Parent or Legal Guardian) please print (Signature of Parent or Legal Guardian)

___________________________________ ___________________________________
(Name of Investigator) please print (Signature of Investigator)

Appendix B

3D Simulation for Physics Education DVD