Virtual reality in the k-12 classroom

by

Sylvia K. Tiala

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Industrial Education and Technology (Industrial Technology)

Program of Study Committee:
Dennis Field, Major Professor
Steve Freeman
Steven Mickelson
Gary Phye
Judy Vance

Iowa State University
Ames, Iowa
2005

Copyright © Sylvia K. Tiala, 2005. All rights reserved.
INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.
This is to certify that the doctoral dissertation of

Sylvia K. Tiala

has met the dissertation requirements of Iowa State University

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

Committee Member

Signature was redacted for privacy.

Committee Member

Signature was redacted for privacy.

Committee Member

Signature was redacted for privacy.

Committee Member

Signature was redacted for privacy.

For the Major Program
To my husband Jim Perkins whose love, support and sense of humor made this dissertation possible.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS vi

ABSTRACT vii

CHAPTER 1. INTRODUCTION 1
  Virtual Reality in Education 1
  Dissertation Organization 1
  Education, Computers and the Cognitive Sciences 2
  Trends and Paradigm Shifts 5
    American workforce 6
    National Initiatives 9
    Learning theories 10
    Neuroscience 13
    Teachers computer literacy 16
  Virtual Reality Within Societal Paradigm Shifts 17
  Putting It All Together 20
  References 24

CHAPTER 2. INTEGRATING VIRTUAL REALITY IN TECHNOLOGY EDUCATION LABS 32
  Virtual Reality in Technology Education Labs 32
  Desktop Virtual Reality System Setup 33
    Software 33
    Sound Effects 35
    Head-Mounted Displays 35
    Tracking Devices 38
  Implementing Desktop VR 40
  References 40

CHAPTER 3. CONCEPT ATTAINMENT IN 8TH GRADE PHYSICAL SCIENCE: MODELS AND VIRTUAL REALITY 42
  Abstract 42
  Introduction 42
  Method 45
    Participants 45
    Environments 45
    Evaluation Instruments 47
    Procedure 49
  Results 51
  Discussion 53
  References 56
ACKNOWLEDGMENTS

This author would like to acknowledge the individuals who helped bring this project to fruition. Special thanks are extended to Judy Vance who has been a mentor and role model for over a decade. Dennis Field proved to be an excellent mentor and major professor. Steve Freeman ensured this author made steady progress on the dissertation. Thank you all for your words of encouragement and persistence. Thanks are also extended to committee members Steve Mickelson and Gary Phye, who took time to participate in the defense process.

Dennis Dorozhkin made the models used in the study and patiently answered a myriad of questions related to virtual reality. I could not have completed this study without his expertise.

Randy Farnum cheerfully provided the classroom and students in which the study was conducted. Eighth grade science students participated willingly and cheerfully. Dave Kapfer, Nate Heying, Joe Kirchoff, Theron Schutte, Sharon Dowd-Jasa, and the Boone Community School Board allowed me to conduct this study at their institution. Thank you all for making this process easier.
ABSTRACT

This dissertation explores the effectiveness of VR as an instructional tool in formal educational settings. Three manuscripts each deal with a different aspect of integrating virtual reality into a middle/high school classroom.

Although, there are no plug-and-play virtual reality solutions currently available to the K-12 teacher, there are easy ways to teach concepts related to VR. The first article discusses the hardware, software, resources and concepts needed to integrate Desktop VR into the technology classroom with a minimal investment of resources.

The second article reports results from a study comparing traditional, model and virtual reality teaching environments. These environments teach concepts regarding simple machines to volunteers from an eighth-grade science class. Nonparametric tests showed a statistically significant concept gain, as measured by scores from concept maps, for students in the model and VR environments.

Cognitive theories of Multimedia Learning, Dual-Coding Theory and Levels of Processing Theory in graphic, model and VR environments are explored in the third article. Students in all three environments showed significant gains from pretest to post-test supporting dual-coding theory and levels of processing theory. Lower test scores for students in the graphics group can be accounted for by the amount of skill needed to mentally construct three-dimensional images from two-dimensional graphics.
CHAPTER 1. INTRODUCTION

Virtual Reality in Education

In the 1990s virtual reality (a type of computer simulation generating three-dimensional models where people immersed themselves using head-mounted displays, projected video, audio feedback and haptic devices allowing real-time computer-human interaction) was being used for military training (Gourley, 1995; Witmer, Bailey, and Knerr, 1996), training firefighters (Bliss, Tidwell, and Guest, 1997), viewing chemical interactions (Illman, 1994), and education (Rose, 1995; Briggs, 1996). After a decade of research, virtual reality (VR), as described above, is uncommon in educational settings. Virtual reality will not be accepted into Kindergarten through twelfth grade (K-12) educational settings until its effectiveness as a teaching-learning tool is demonstrated.

The manuscripts included in this dissertation explore the effectiveness of VR as an instructional tool in formal educational settings. Each manuscript deals with a different aspect of integrating VR into the middle/high school classroom.

Dissertation Organization

The first manuscript in this series concentrates on making the complexities of integrating hardware and software into a useable and inexpensive (under $4,000) VR system comprehensible for high school teachers. This article is intended to provide an impetus for other high school teachers to integrate VR applications into their classroom. Research regarding the impact of VR on learning may take place as instructors integrate VR into their teaching methodologies. Thus, this article represents a critical “first step” in VR research in K-12 educational settings. It explains how VR is incorporated into a graphics lab.
The second article examines concept attainment by eighteen volunteers from an eighth grade science class. This quantitative study examines academic gains, measured by written tests and concept maps, for students exposed to either a traditional lecture environment, a teaching environment using models or a teaching environment using virtual reality. Can virtual reality be used to effectively teach abstract concepts related to simple machines? Does it work? The study and related article investigated the potential of virtual reality as a teaching tool.

The final article examines virtual reality as an environment with potential to motivate students. Cognitive theories from Multimedia Learning, Dual-Coding Theory and Levels of Processing Theory (ChanLin, 1994) were used to explain how virtual reality may enhance concept attainment. The article looks beyond written tests to the robust mental models students bring to a teaching-learning scenario.

**Education, Computers and the Cognitive Sciences**

With computer technology pervading American culture, 70% of US children between age 3 and 17 have access to computers (Child Trends 2003; DeBell and Chapman, 2003) and 70% of today’s college students play video games (Riegle, 2004). Electronic gaming (Novak, 2005), simulations and virtual reality are being investigated as educational tools (Barab, Thomas, Dodge, Carteaux, Tuzun, 2005; Bierman, 2005; Din and Caleo, 2000; Marinelli and Pausch, 2004; Robertson and Good, 2005; Shim et al., 2003). Simulators as defined by Tracey (1992) are “machine(s), device(s), or process(es) designed to assume the appearance, characteristics, or capabilities of a system or item on which training is required.” Virtual reality is a subset of simulation as shown in Figure 1.1. Three attributes of simulations in training environments as defined by Blaiwess and Regan (1986)
Figure 1.1. Virtual reality as a subset of simulation

are 1) replicating the real world, 2) providing hands on practice, and 3) skill development. Virtual reality has the same attributes of simulations. That is virtual reality can be used to replace the real world, provide hands on practice and develop skills but they also have attributes defining them as special instances of simulations. Virtual realities use computer-generated models while simulations may include mock-ups, card games (California State University, 2002) or computers (Blaiwess & Regan).

Electronic games are also a subset of simulations that share some elements with virtual reality. Electronic games, like virtual reality, are designed to engage participants in a computer-generated world, manipulate otherwise unalterable variables, enable individuals to alter perspectives, observe behavior over time, view events in three dimensions and provide immediate feedback (Squire, n.d.).
Cognition, knowing and thinking (Woolf, 1974; Pressley and McCormick, 1995), is the main focus of formal K-12 educational settings. Connections among cognitive sciences were mapped by the Sloan Foundation in 1978, cited in Gardner (1985), and help frame discussions about games, simulations and virtual reality's role within the formal school environment. Philosophy, psychology, neuroscience, artificial intelligence, linguistics and anthropology interact to help describe human cognition and learning. Figure 2 shows how traditional school environments, computer environments and human-computer interfaces provide a context to which principles from philosophy, psychology, neuroscience, artificial intelligence, linguistics and anthropology can be applied. Traditional educational

**Figure 1.2. Cognitive sciences in context**

environments use lectures, questioning techniques and other human-human interactions. Computer-computer interactions include computers operating autonomously to serve software applications, control machines, or operate telecommunication networks. Human-computer interfaces include electronic games, simulations and VR. Elements of cognitive sciences apply to both human beings and to the computer technologies involved in the
teaching-learning process. Anthropology is used to investigate the human-human or the human-computer interaction of instruction. Dialogs are created between people when they interact face-to-face, use the Internet, or within the context of a game, simulation or VR. These dialogs, or interactions, are explained through the study of linguistics, psychology, artificial intelligence and neuroscience. The dialogs are framed within a context that individuals believe are beneficial or rewarding. Thus philosophy and psychology (Gardner, 1985) are included in examining the teaching-learning process for both human-human and human-computer learning environments. Research into specific aspects of the cognitive sciences, such as psychology, neuroscience, or computer science, allows the separation of the human being from the computer. In human-computer interfaces however, the computer application cannot be teased apart from human performance. For example, Walairacht, Yamada, Hasegawa, Koike, and Sato's (2002) research discusses the algorithms used to merge real and virtual images using computer algorithms, hardware and software while Schubert, Friedmann and Regenbrecht (2001) examines the cognitive processes leading to a sense of presence in a virtual reality. Although Walairacht et al.'s paper focuses on computer technology and Schubert et al.'s paper focuses on cognitive processing, both studies directly or indirectly used the aforementioned elements of cognitive psychology.

**Trends and Paradigm Shifts**

Systemic changes are occurring in American education. As society changes, educational theory advances, technological systems improve and government mandates are enacted. Exploring the paradigm shifts accompanying these systemic changes helps one understand the conditions needed for virtual reality to be considered an effective instructional tool in educational environments. Examination of these trends helps delineate
areas of research relevant to virtual reality and virtual environments. Impetus for including virtual reality as an instructional method in K-12 education will occur as research concerning the skills of America’s workforce combine with government initiatives regarding student achievement (anthropology), new learning theories (psychology) and advances in neuroscience.

**American workforce**

During the 1990s American society was part way through an economic and technological revolution that started in the 1970s (Snyder and Edwards 1992). Snyder and Edwards claim that the United States’ falling rate of productivity, the increasing trade deficit, and Third World nations’ improvement of productivity and skilled labor are major threats to Americans’ standard of living. America’s workforce diversified as 13.5 million immigrants entered the United States (United States Immigration and Naturalization Service, 2003) between 1990 and 2000, the workforce aged and more women started working (United States Census Bureau, 2002). The changing demographics of the American workforce combined with America’s transition from a manufacturing-based economy to an information-based economy left corporate America with a lack of skilled employees.

In 1993 *Training Magazine* reported that over 20% of U.S. organizations with 100 or more employees were providing remedial education in Math, Reading and Writing for graduates of American High Schools. Remedial training in Math, Reading and Writing, for employees who speak English as a second language, was provided by over 48% of the organizations with 100 or more employees the same year. Fifty-three percent of the participants in the remedial training programs, designed for people speaking English as a second language, were graduates of American high schools (Froiland, 1993). Three years
later the statistics became a trend as remedial courses in Reading, Math, Writing and English were still offered by 38% - 47% of the organizations surveyed (Industry Report, 1996). During the 1990s it became clear that the American education system was not producing the qualified workers needed to maintain productivity and competitiveness at the global level.

Training data from companies with employees of 100 or more reflects these trends. Figure 1.3 was derived from a decade of reports from Training magazine. Classroom

![Graph showing percent used of different instructional methods from 1993 to 2001](image)

**Figure 1.3.** Nine years of instructional media and methods (Froiland, 1993; Industry Report, 1995; Industry Report, 1996; Industry Report, 1997; Industry Report, 1998; Industry Report, 1999; Galvin, 2001)

---

4 Note: Training changed data gathering methods for its annual report in 2002. Data is not reported after 2001 because of this change.
instruction is used for training 90% of the time while workbooks and manuals are used between 70% and 80% of the time. This trend has remained relatively stable and probably reflects the remedial training employees need in basic Reading, Writing, Math and English. Companies with more than 100 employees indicated they used computer-based training, games and simulations (both computer-based and non computer based) between 28% and 65% of the time with large fluctuations in use each year. Virtual reality has been used less than 5% of the time for training in American companies over the past decade. This trend has remained stable but is changing. Training Magazine's 2001 analysis of training (Galvin, 2001) indicates that an additional 15% of survey respondents “seldom” use virtual reality as a training tool. For the first time in a decade of analysis there are indicators that virtual reality is gaining a foothold in training environments. D'Cruz, Stedmon, Wilson, Modern and Shaples' (2003) research to develop a holistic, user-centered approach to virtual environments for manufacturing applications and Troyer, Bille, Romero, and Stuer's (2003) research regarding easier generation of virtual worlds further indicates that VR applications may be increasing within American business and industry environments. VR applications may become more important as companies globalize. VR applications may help companies design products more efficiently without building physical prototypes. Thus corporations would save money. Three-dimensional images created with VR applications may be beneficial to design teams who work together on projects but do not share a common language and who work remotely from one another. The fact that VR is not prevalent in training does not mean it is not used in corporations. Remediating basic skills for the working population does not require the higher-end VR applications related to design, analysis and engineering.
National Initiatives

The American government took heed of societal changes. The National Commission on Excellence in Education (1983) found that American students did not possess the skill level needed to compete effectively in a global economy. Eight years later the Secretary’s Commission on Achieving Necessary Skills (SCANS) report called for schools to be transformed into high-performance organizations (June, 1991). The SCANS Commission found that over half of the students graduating from American schools lacked the basic academic skills, thinking skills, and personal skills needed to be successful in the modern working environment. The inclusion of thinking skills that incorporated decision making, problem solving, reasoning and “seeing things in the mind’s eye” (processing symbols, pictures, graphs, objects and other information) impacted curriculum reform efforts for the next decade (Secretary’s Commission on Achieving Necessary Skills, 1991).

The American Association for the Advancement of Science (1993) published standards describing what all American students should be able to know or do. In addition to core concepts, the science standards called for learning that addressed the particular needs and interests of individuals, reducing the memorization of facts that impeded the acquisition of understanding, cross-curricular connections, and learning in many different contexts. The National Council of Teachers of Mathematics (2001-2004) updated their curriculum standards in 2000. Core mathematical concepts were included in five content standards. Process standards included communication, making connections through multiple perspectives, and representing mathematical ideas with the use of concrete materials, tables, graphs, symbols, spreadsheets and so forth. Reflexive thinking and students actively building new knowledge using experience and knowledge were also called for by the
National Council of Teachers of Mathematics. Technology standards calling for an understanding of The Designed World (ways resources are used to develop products and systems) that integrated knowledge across the curriculum were published in 2000 (International Technology Education Association). Active learning, teamwork, and real-world problem solving were included in these standards. These new standards reflected a change in cognitive psychology and learning theory models that were being developed during the second half of the twentieth century. These new theories and models impacted instructional methods used in the classroom.

**Learning theories**

Howard Gardner explains how Behaviorism, quantifying human behavior through observation, predominated educational research and practice during the first half of the twentieth century. During the 1948 Hixon Symposium, mathematician John von Neumann compared the computer to the human brain; neurophysiologist Warren McCulloch led a discussion on how the brain processed information; psychologist Karl Lashley laid out a new research agenda that challenged behaviorist ideas. The Hixon Symposium laid the groundwork for the Symposium on Information Theory held at the Massachusetts Institute in Technology in 1956. Allen Newell and Herbert Simon demonstrated the first proof of a theorem completed by a computer. Noam Chomsky demonstrated a mathematical approach to grammar while George Miller claimed that human short-term memory was limited to approximately seven characters. After the 1956 symposium the new field of cognitive science was officially recognized (Gardner, 1985).

Spurred by these symposiums over forty new learning theories and models of cognition were proposed and discussed in psychology and educational research.
communities. Table 1.1, shown below, highlights some of these theories as described by the educational psychologist Greg Kearsley (1994-2003). At the end of the twentieth century Constructivism, a learning philosophy based on constructing and adapting mental models

Table 1.1. Learning theories from Greg Kearsley (1994-2003)

<table>
<thead>
<tr>
<th>Year Introduced</th>
<th>Person(s)</th>
<th>Theory Name</th>
<th>Main Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>J. Gibson</td>
<td>Information Pickup Theory</td>
<td>Past experience plays a dominant role in an active organism’s role in perception.</td>
</tr>
<tr>
<td>1971</td>
<td>A. Pavio</td>
<td>Dual Coding Theory</td>
<td>Equal weight should be given to the verbal and nonverbal (image) processing systems when exploring human cognition</td>
</tr>
<tr>
<td>1979</td>
<td>F. Craik &amp; R. Lockhart</td>
<td>Levels of Processing Theory</td>
<td>Separate stage for sensory, working and long-term memory. Information will be remembered over a long term if there is a “deep” level of processing linked to strong visual images or numerous associations with existing knowledge.</td>
</tr>
<tr>
<td>1979</td>
<td>G. Salomon (in Pressley &amp; McCormick, 1995)</td>
<td>Symbol Systems Theory</td>
<td>Schema, “a chunk of information stored in long-term memory” specifies how a number of concepts relate to one another. The processing of media and extracting meaning from a given medium depends upon the learner. Media also create new schema that in turn affects an individual’s cognitive processing.</td>
</tr>
<tr>
<td>Year Introduced</td>
<td>Person(s)</td>
<td>Theory Name</td>
<td>Main Ideas</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>1982</td>
<td>H. Gardner</td>
<td><em>Theory of Multiple Intelligences</em></td>
<td>Individuals possess and use several forms of intelligences in varying degrees. Intelligences include linguistic, musical, logical, mathematical, spatial, body-kinesthetic, intrapersonal and interpersonal skills.</td>
</tr>
<tr>
<td>1986</td>
<td>Wigström &amp; Gustafsson (in Kandel and Hawkins, 1992)</td>
<td></td>
<td>Wigström &amp; Gustafsson build on Hebb’s and Tauc’s work describing how associative learning takes place at the cellular level. Biochemical changes occur in the brain’s hippocampus and are important for spatial learning. Neither associative nor spatial learning require complex neural networks.</td>
</tr>
<tr>
<td>1988</td>
<td>Spiro, Feltovitch &amp; Coulson</td>
<td><em>Cognitive Flexibility Theory</em></td>
<td>The theory was designed to support the use of interactive technology. Effective learning is context-dependent and learners need an opportunity to develop their own representations of information in order to learn properly.</td>
</tr>
<tr>
<td>1988</td>
<td>J. Lave’s</td>
<td><em>Situated Learning Theory</em></td>
<td>A general theory of knowledge acquisition arguing that learning, as it normally occurs, is an activity within a context and a culture. This contrasts with classroom setting where learning activities involve teaching/learning abstract knowledge out of context.</td>
</tr>
<tr>
<td>1993</td>
<td>J. Bransford and The Technology Group at Vanderbilt University</td>
<td><em>Anchored Instruction paradigm for technology-based learning</em></td>
<td>Instruction includes complex, realistic problems anchored in a context that encourages active construction of knowledge and exploration by learners</td>
</tr>
</tbody>
</table>
based on personal experiences (Funderstanding, 1998-2001), was impacting classroom methodology. The push toward Constructivist philosophy as reflected in the aforementioned learning theories call for active participation by the learner, a need for the learner to construct her/his own knowledge, the use of multimedia to deliver information and/or complex and realistic problems anchored in context. Surrounding students with a virtual reality where there is a feeling of presence (being there), the engagement of senses or immersion (Schuemie, van der Straaten, Krijn, & van der Mast, 2001), while using three-dimensional computer simulations to construct meaning within a context is clearly anchored in a constructivist philosophy of learning.

**Neuroscience**

Neuroscience, the study of the brain, helps explain how an individual’s experience affects the brain. Kandel and Hawkins (1992) study with snails describe the biochemical process involved in strengthening existing synaptic connections for short-term memory and the activation of genes and the growth of new synaptic connections needed for creating long term memories within the brain. Buckner (2000) claims that the brain’s hippocampus is active when remembering context-rich information. This contrasts with reading text in a two-dimensional environment (computer screen) where the human prefrontal cortex is retrieving archived information and combining it with moment-to moment awareness that engages an individual’s working memory (Shatz, 1992). Donner’s drawing (from Fischbach, 1992) of the human brain is included in Figure 1.4 for reference.
The idea that brain synapses and cortical maps are dynamic and continuously modified by experience (Buonomano & Merzenich, 1998) gained impetus in the neuroscience community in 1983. Merzenich, Kaas, Wall, Nelson, Sur and Felleman demonstrated that brains of adult primates rewired themselves after nerve injuries. Pons, Garraghty, Ommaya, Kaas, Taub and Mishkin’s 1991 study showed “large scale” brain reorganization in the somatosensory cortex of macaque monkeys (Jain, 2002). Recanzone, Schreiner and Merzenich (1993) showed that monkeys trained with an auditory frequency discrimination task developed a larger A1 cortical area representing the trained frequencies. Human brains can rewire themselves as Hofman, Van Riswick and Van Opstal (1998) found when auditory space maps improved in adult humans who were fitted with molds in the
concha of both ears that disrupted sound elevation cues. Sound localization steadily improved and stabilized over six weeks in the sound disrupted ears. With molds removed subjects were able to accurately locate sounds with accuracy as high as before the experiment began. This suggests that two different neural representations of auditory cues were present. Buonomano and Merzenich (1998) reviewed studies demonstrating the remapping of cortical areas in monkeys, raccoons and cats after denervation or amputations, the reorganization of the visual cortex in cats with lesioned retinas, and reorganization of tonotopic maps in lesioned ears of guinea pigs. These studies show that animal brains can reorganize nonresponsive cortical areas deprived of stimuli to respond to other sensory inputs. Neurogenesis, the generation of new neurons in the brain, has been shown in the hippocampal dentate gyrus of adult macaque monkeys (Kornack and Rakic, 1999) and that the generation of these neurons in adult marmoset monkeys is negatively affected by stress (Gould, Tanapat, McEwen, Flügge and Fuchs, 1998). Eriksson, et al. (1998) demonstrated that the human hippocampus generates neurons throughout life.

Virtual reality is being incorporated in neuroscience to provide environments that evoke brain responses and behavior (Pugnetti, Meehan and Mendozzi, 2001) and study spatial ability and mental rotation skills (Rizzo, et al., 2001). North, North and Coble (1997, 1998) are using virtual reality to treat psychological disorders. Tarr and Warren (2002) are using virtual reality to study route navigation and optic flow.

Neuroscience combined with virtual reality research challenges the traditional behaviorist view of an inactive nervous system responding to stimuli (Gardner, 1985) and helps constructivists argue their case for context-rich educational environments requiring
active learners. This in turn helps justify using VR as a teaching tool in formal K-12 educational settings.

**Teachers’ computer literacy**

Statistics show that K-12 classroom teachers lag behind their students in computer usage and comfort level with computers. Older teachers are not as comfortable using computers and computer applications as their younger counterparts (Rowand, 2000).

During the last decades of the 20th century industry spent billions of dollars building information technology networks using fiber-optic cables, electronic mail, web sites, and so forth. As predicated by the futurist John Naisbitt, the structure of formal educational institutions is changing as education programs are offered via interactive television or via the Internet (Snyder and Edwards, 1992). “Virtual” organizations, using computers and the associated hardware to interact, include virtual universities (Michigan State University, 2003), virtual communities (Serim, 1996; Rheingold, 1998), virtual teams/organizations (Penn State University, 1999-2003), and virtual museums (Verna & Grumbach, 1998; IEEE Virtual Museum, 2003; National History Museum, 2003; Metropolitan Museum of Art, 2000-2003) are commonly found on the World Wide Web. In each of the applications the delivery can be at the same time (synchronous) or delivered at different times (asynchronous). Synchronous delivery is important only when people at remote locations need to participate in a given event at the same time. Sending and receiving rates within a virtual environment are determined by hardware. Virtual universities, virtual corporations and virtual communities interact in real time and are constrained by real-life deadlines. Due dates are adhered to, meetings need to occur, deliveries need to be made and so forth. A
degree of computer literacy is required to log on to a computer network, download and upload information in all of these scenarios.

During the 1993 school year, 59% of American students used computers at school, 27% of American students used computers at home and 14.8% of American students used computers at home to complete schoolwork (National Center for Education Statistics, 2002). By 2001 seventy-eight percent of American students used computers at school and 69.4% of American students used computers at home to complete schoolwork. Not only has students’ computer usage increased but the type of computing has grown increasingly complex. Word processing, database, spreadsheet, computer-aided drafting, web design, flash animation, digital photography and publishing applications are commonly found in today’s high schools. In 1999 sixty-six percent of public school teachers with access to computers indicated they used the computer for classroom instruction but only 33% of the teachers felt well or very well prepared to use computers in teaching (Rowand, 2000). Thirty-one percent of teachers with 3 or fewer years of teaching felt prepared to use computers or the Internet in teaching while only 19% of teachers with 20 or more years of experience feel comfortable using computers in their classroom (Rowand, 2000). Either current teachers will need to increase their technological literacy or implementation of virtual environments will have to wait until today’s technically savvy youths enter the teaching field.

Virtual Reality Within Societal Paradigm Shifts

American corporations are concentrating on improving the basic math and reading skills of their workforce. If Snyder and Edwards’ (1992) analysis of the cycle of societal change is correct, the time is right for virtual reality to be accepted into educational institutions. Students growing up with technology on their desktops are starting to enter
the workforce. Lumsdaine and Lumsdaine's (1995) paradigm life-cycle curve is used to examine how paradigm shifts within corporate America, educational psychology, neuroscience, and education will converge to create conditions conducive to implementing virtual reality in formal educational settings. According to Lumsdaine and Lumsdaine:

Paradigms as tools for problem solving have a life cycle in the shape of a typical S-curve as shown in Figure (1.5). In the early phase (Segment A), problem solving is slow because of the learning curve and because only a few pioneers are beginning to use the paradigm. During the main phase (Segment B), problem solving with the paradigm is quite successful and is getting well established, although some "impossible" problems are set aside in the hopes that further development with increased experience, refinement, and precision will help in solving these cases. In the last phase (Segment C), problem solving becomes more costly, more time-consuming, and less satisfactory, not only because the problem solved in this stage are more difficult problems but also because the solutions no longer fit the larger context because of changes that have occurred elsewhere.

Unresolved problems create a feeling of uneasiness and uncertainty - a climate that encourages outsiders to look for a new paradigm, even though the current paradigm is still very useful and doing well in solving most problems in its field. This stage of creative thinking by the outsider is shown by the thin vertical lines in Figure (4). Once these so-called paradigm shifters are beginning to be successful in solving problems the new way, they are joined by the paradigm pioneers, the people who are adopting the new paradigm and helping to bring about change. This shift may happen over a period of time, as indicated by the hatched area. Note that the problem solving now has shifted to a new S-curve. Paradigm pioneers take the risks and reap benefits. When an organization or a person delays making a decision to adopt a new paradigm, it will take a much larger effort and higher cost to catch up and recapture a competitive position later.

Figure 1.6 shows how paradigms used by American business, neuroscience, educational psychologists exploring learning theories, universities and K-12 education institutions converge on a new S-curve. Paradigms have shifted in every area over the last two decades.

---

Figure 1.5. Lumsdaine and Lumsdaine's paradigm life-cycle curve

Figure 1.6. America shifts to a new paradigm s-curve

---


with the exception of K-12 education. While most of American society is operating on a new information-based S-curve, K-12 education bypassed the transition zone to a new problem-solving S-curve and is operating under old paradigms suitable for a manufacturing-based society. When K-12 education paradigms shift to the new S-curve, the conditions will be suitable for implementing virtual reality in corporate and educational environments. Extra effort and resources will be needed for formal education institutions to catch up to today's information-based society when the current paradigm shifts.

**Putting It All Together**

When designed correctly, virtual reality provides more than a graphical human-computer interface. It provides an experience from which one can form concepts, examine relationships and analyze data. This relates to constructivist learning theories that, Winn (1993) argues, provide a valid and reliable basis for using immersive VR in education. There are some pioneers that are using VR in education. Examples include: Ludwig's (1996) use of VR to study geography, Savides' (2002) use of VR to teach life skills, Moschell, Hughes and Loftin's (1999) linking of VR to Robert Gagné's categories of learning. Additional research may provide impetus for change in educational environments.

Advances in neuroscience demonstrate how VR relates to learning. Neuroscientists are exploring ways experience impacts brain structure (Miller, 2000). Electroencephalographic (EEG) technologies, positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are used to examine how the brain processes information (Poldrack, 2000). Meehan and Mendoza (2001) describe how EEG, skin temperature, skin resistance, heart rate, and so forth correlate to human performance in virtual environments while virtual reality is used to test theories of perception (Warren, Kay,
Zosh, Duchon and Sahuc, 2001; Tarr and Warren, 2002). Neuroscientists are no longer using an old paradigm of an inactive brain responding to stimuli (Gardner, 1985, p. 13) but have shifted to a new paradigm curve to an active, parallel-processing brain that structures itself through experience.

Some higher education and informal education institutions have changed to a new paradigm curve and are structuring educational opportunities via computer networks. Evidence of this paradigm shift is seen in the rise of virtual universities, virtual museums, online tours and the like. Discussions now center on issues such as teaching strategies, scalability, effectiveness and limitations of distance education (American Federation of Teachers, 2001; State University of West Georgia, 2004).

As of 2001 one in five high school students didn’t have the basic reading and math skills necessary to be successful in the workplace. This lack of basic skills cost corporate America about $60 billion a year in lost productivity (Baynton, 2001). At the same time educational spending in America increased from about $9 billion (constant dollars) in 1990 to about $22 billion in 2001 (constant dollars) while only 32% of America’s 4th graders read proficiently and approximately 20% of America’s twelfth graders were proficient in math or science (United States Department of Education, n.d.). Congress passed the No Child Left Behind Act of 2001 (U. S. Department of Education, 2002) that include sanctions (withholding of funds) and rewards (bonuses and recognition) to hold local educational agencies and public elementary schools and secondary schools accountable for student achievement during systemic reform. This impacts the implementation of virtual reality in K-12 education in several ways. First, emphasis on student achievement in math, science and English in kindergarten through twelfth grade has focused funding on improving basic
skills. Little time and money is being focused on new instructional technologies. Second, the No Child Left Behind (NCLB) Act emphasizes standardized testing with valid and reliable assessments. There are no standardized tests with established validity and reliability that are available for measuring the effectiveness of VR in K-12 education environments. Third, the philosophical approach to meeting the requirements of NCLB is behaviorist while the philosophical approach to learning in virtual environments is constructivist. Behaviorists rely on observable and measurable behaviors (such as standardized tests) and discount mental activities that can’t be observed or measured (Funderstanding, 1998-2001). Constructivists advocate hands-on problem solving, custom curricula geared to a student’s prior knowledge and the elimination of standardized curriculum (Funderstanding, 1998-2001). The two philosophies result in radically different teaching and assessment practices. Fourth, teachers lag behind their students in use and comfort level in computer use. Teacher’s skills will need to be enhanced since virtual reality is a computer intensive activity. Finally, there is lack of evidence that virtual reality is an effective teaching-learning strategy.

It becomes clear that K-12 education has neither increased its effectiveness nor kept pace with the rest of society at changing paradigms and updating instructional technologies. As systemic change occurs and K-12 education shifts to a new paradigm curve, virtual reality may be utilized as an instructional tool. Key criteria needed to bring VR into educational environments include:

- Enhancing educators’ computer literacy
- Developing theoretical constructs regarding virtual reality as a teaching-learning medium
• Developing valid and reliable assessment strategies applicable to virtual reality learning environments

• Collect data showing how virtual reality can impact productivity and learning

If people learn by experience then virtual reality should be an effective teaching technology. Siegel and Hanson (1992) indicate that educational experiences such as learning nursery rhymes, swimming lessons, visiting museums, or attending concerts contributed to students' reading achievement. The U. S. Department of Education (n.d.) claims that 68% of students who can't read well are minority students or those living in poverty. Experience, not economics, may be the key to greater school achievement for these disadvantaged youths. Students lacking diverse experiences may have more difficulty extracting information from crudely drawn sketch on a teacher’s blackboard than students with diverse experiences. Virtual reality may level the instructional playing field by giving all students experience in a synthetic environment from which discussion, activities and learning can proceed. Helping students build on personal experiences in a hands-on virtual reality ties into a constructivist philosophy of education. Educators focus on students' multiple intelligences, learning styles and brain compatible learning. At the same time research in cognitive psychology is fueled by neuroscientists arguing that virtual reality helps restructure neural connections within the brain. Pressley and McCormick (1995) describe episodic memory, semantic memory, building schema, and dual coding elements of cognitive psychology that might be explored using virtual reality.

The goal of this dissertation is to apply concepts related to psychology, human-computer interfaces and learning theory to real-life educational settings. The articles included in this paper were designed to address three of the key criteria needed to bring VR
into K-12 educational settings. The first article addresses educators' computer literacy. *Integrating Virtual Reality in Technology Education Labs* is written for high school Industrial Technology teachers who are interested in incorporating virtual reality into their classroom. The second article explores how virtual reality impacts student learning. Does virtual reality work as an instructional method? The final article uses Dual-Coding Theory and Levels of Processing Theory to explain why VR works as an instructional tool.

**References**


Robertson & Good (2005) Story creation in virtual worlds. *Communications of the Association for Computing Machinery* volume 48 no. 1 pp 61-65


CHAPTER 2. INTEGRATING VIRTUAL REALITY IN TECHNOLOGY EDUCATION LABS

A manuscript intended for submission to The Technology Teacher

Sylvia Tiala

Virtual Reality in Technology Education Labs

Desktop Virtual Reality (VR) is a three-dimensional (3D) computer environment viewed through a head mounted display (HMD). Individuals are provided with a sense of being present in the virtual world using control devices that allow human-computer interaction and navigation (Ausburn & Ausburn, 2004). VR, HMDs and trackers can be easily and inexpensively integrated into the Technology Education laboratory. Exposure to desktop VR introduces students to technologies used in movie animation, electronic gaming (Novak, 2005), chemistry (Illman, 1994), surgery, flight simulation (Shulman, 1999), marketing, engineering, military training, and robotics, (Briggs, 1996; Wong & Wong, 1996). Television screens, computer monitors or head-mounted-displays (HMD), and small display screens mounted in a helmet, give feedback to gamers, animators, surgeons, pilots, or others using virtual worlds. Input devices, such as mice or wearable gloves controlling a computer (data gloves), allow users to direct cameras, robots, buttons and sliders in

---

1 This research was supported by NSF Research Experiences for Teachers DMI # 0084876


3 Accepted for presentation at the 68th ITEA Conference, March 23-25, Baltimore, Maryland.

4 The author wishes to acknowledge the efforts of Ben Janke, Iowa State University, for helping integrate VR hardware with Alice environments.
simulations and VR. Gamers interact with their environments using directional pads, thumb sticks and triggers.

Integrating varied technologies to make three-dimensional stereographic computer worlds is an exciting educational prospect. Although, there are no plug-and-play virtual reality solutions currently available to the K-12 teacher, there are easy ways to teach concepts related to VR. Experimenting with hardware and software can be time consuming for the K-12 teacher. This article discusses the hardware, software, resources and concepts needed to integrate Desktop VR into the technology classroom with a minimal investment of resources.

**Desktop Virtual Reality System Setup**

**Software**

Software applications drive the selection of computer hardware and the associated input/output peripherals in any VR system. *Alice*, a freeware computer program from Carnegie-Mellon University, available for downloaded from http://www.alice.org, may be used as the starting point for Desktop VR. Minimum specifications for running *Alice* include Windows 2000, Windows ME, or Windows XP running a PC with a minimum speed of 500 MHz. Experiments for this article were conducted using a “slow and steady” version of Alice on a PC running Windows 2000 at 450 MHz with excellent results. A VGA graphics card with 16 bit color, 128 MB of RAM, a sound card, and a video resolution of 1024 x 768 is needed (see http://www.alice.org for preferred specs). *Alice* integrates into graphics and web design classrooms easily since computer workstations running modern CAD and graphics packages will easily run *Alice*. *Alice*’s interface, shown in Figure 2.1, is used as the starting point for a first-time introduction to virtual reality for the following reasons:
• Three-dimensional objects are built and ready for animation.

• *Alice* is free from Carnegie-Mellon University and is regularly updated.

• Programming skills needed to implement higher-level VR systems are introduced while students create their own animated environments.

• Components of *Alice* have cross-curricular ties to math (moving objects along 3 axis or absolute versus relative coordinate systems), science (reflectivity or opaqueness of objects and sound wave frequencies) and language (learning a computer language).

• *Alice* is easy to download and use with directions from the *Alice* website. Built-in tutorials and a beta version of Dann, Cooper and Pausch's (2005) instructional text *Learning to Program With Alice* (http://www.alice.org) provide additional support.

• Results of programming can be seen immediately.

![Figure 2.1. Carnegie Mellon University's Alice interface downloaded from http://www.alice.org (Permission granted: Randy Pausch)](image)

Students will be able to program *Alice* Worlds in a short time span. Experience shows that students can animate single characters proficiently after five hours of practice. Many students will be able to develop interactive animations that integrate head-mounted-
displays by the end of a twelve-week semester. Multi-character, three-minute interactive animations are easily accomplished.

**Sound Effects**

Sound effects add another dimension to animations and can be added directly to an *Alice* environment after plugging in an external microphone. Science concepts relating to sound waves and careers in sound production applicable to movie production, animation and audio recording can be addressed while creating *Alice* worlds. Students open their *Alice* world, select an object, and choose the `record sound` tile under the `properties` > `Sound` tabs. Adding sound using the default recorder in a Windows XP system is accomplished by choosing the `start` > `All Programs` > `Accessories` > `Entertainment` > `Sound Recorder` tabs and recording sound. The saved .wav or .mp3 sound file is imported into an *Alice* world using the `import` tile under the `properties` tab for an object. Figure 1 shows a rabbit, a frog and a beach chair. In this animation the frog jumps out from under the chair and hops toward the lake. A sponge repeatedly dipped into a pail of water was used for the sound track of a frog jumping. Students can experiment with recording, echoing, speed and volume of sound to get the desired effects.

**Head-Mounted Displays**

A head-mounted-display (HMD), similar to that shown in Figure 2.2, projects a VR world in front of a person’s eyes and is needed for stereo imaging in a desktop VR system. HMDs range from the size of a large helmet to the size of a pair of eye glasses (http://www.i-glassesstore.com; http://www.stereographics.com). Images appear three-dimensional by projecting slightly different views of the same object into the left and right eye (StereoGraphics Corporation, 1997; Bungert, 1998). Care should be taken when selecting a
HMD as people can experience nausea, fatigue and dizziness if the HMD’s resolution and refresh rates are too low. StereoGraphics Corporation (1997), General Reality Company (n.d.a; n.d. b), Bungert (1998) or other experts should be consulted for technical considerations inherent in choosing a viewing device.

Stereo images and 3D graphics are both required for VR applications. It is important to understand the difference between 3D graphics and stereo graphics as some software/hardware vendors interchange these terms.

Three-dimensional (3D) objects, like those shown in Figure 2.3, have width, height and depth while two-dimensional objects have only width and height. Three-dimensional objects are critical components for desktop VR worlds. Many computer-aided-drafting packages (CAD) and modeling/animation packages generate 3D objects and virtual worlds that a user can move through. The viewer is able to see the front, back, top, sides and bottom of objects and their respective positions within a world.
Figure 2.3. Three-dimensional objects versus two-dimensional objects.

Stereoscopic views are created when software and hardware splits lines or pixels of a computer image into a left and right image and sends these to a display screen or HMD. Interlaced stereo, segment/line sequential, or dual stream techniques are a few ways stereo images are created (Lipton, 1996-97). Images that don’t converge (parallax), similar to that seen through binoculars or through the toy View-Master® viewer, are examples of stereoscopic imaging (StereoGraphics Corporation, 1997). Stereo graphic cards in conjunction with HMDs and CAD/illustration software capable of generating stereo images (alternating left and right views) is the easiest method of importing stereo images into a desktop VR. Third party software packages integrating hardware and software are available, but require C language programming skills.

Although current versions of Alice do not support stereo imaging, connecting a HMD to a computer is useful for conveying concepts related to stereo imaging and hardware/software interfacing. iO Display Systems’ i-glasses PC is a low-priced ($699) yet fairly rugged HMD that includes stereo sound through built in speakers and a video resolution of 800 x 600 pixels. The i-glasses PC runs Alice worlds at an 800 x 600 pixel resolution. The i-glasses PC is available with either serial or USB connections and was designed for computer-generated images and not for television viewing. This is an
important detail to check when ordering a HMD as it affects the way stereo images are projected. Connecting the *i-glasses PC* is easy using video Y adapters allowing a user to view an image in the HMD and on the computer monitor at the same time. Some dimming occurs using this method. Dimming problems are resolved by using a second graphics board or a video card with two video outputs. A DVI-VGA adapter can also be used to view VR worlds in the HMD and on the computer screen at the same time. Setup is fairly easy by following the *i-glasses PC* manufacturer’s directions and setting up the *i-glasses PC* as a second monitor using the *start>Help and Support>Hardware>Monitors>Multiple Monitors* menus in *Windows XP*.

**Tracking Devices**

Tracking devices like that shown in Figure 2.4, add an element of interactivity with a computer-generated world. Trackers connected to HMDs send signals to a receiver. The receiver sends positioning information to the computer and adjusts the user’s view depending on where the head is located and how it is positioned in a virtual reality. There are several things to consider

*Figure 2.4. Tracking device. Source: Sylvia Tiala*
when selecting tracking devices. Cost is the major factor as trackers range in price from several hundred dollars to tens of thousands of dollars. Degrees-of-freedom refers to what types of motion a tracker will register. A three degree-of-freedom tracker usually picks up pitch (up and down), roll (side to side) and yaw (left and right) motions of a head or hand. This is adequate for a person sitting in a chair and moving their head. A six degree-of-freedom tracker will pick up pitch, roll and yaw as well as register placement along the x, y and z coordinates of a virtual world. A six degree-of-freedom tracker places the viewer inside a world and indicates head position and orientation. Two three-degree-of-freedom trackers can not be combined into a six-degree-of-freedom tracker as both trackers will register only pitch, roll and yaw. Since many low-end trackers are limited to ten feet or less of motion, range of operation should also be considered.

Integrating trackers into a desktop VR system provides an opportunity to teach students about relative, absolute and polar coordinate systems and calibrating scientific instruments for accurate readings. Trackers are easily configured to function as a mouse. This is usually accomplished within the computer’s operating system or within a software package that supports a particular tracker. One should refer to individual games, CAD programs, or simulation specifications for a list of trackers supported. Maui Innovative Peripheral’s Cymouse, shown in Figure 2.5 is an inexpensive ($89) six-degree-of-freedom tracker that is easily integrated with Alice using mouse emulation. Some modification may be needed to affix the tracker securely onto a computer yet allow for removal and safe keeping. Tracker range is limited to several feet due to cord lengths and tracker/receiver sensitivity. Tracking is jittery at times and positioning the tracker and receiver for calibration requires precise alignment. Integrating this hardware into the desktop
VR system allows students to see how the 3D software, peripheral hardware, and programming skills combine to produce an interactive computer-generated world.

Implementing Desktop VR

This article concentrates on making the complexities of virtual reality hardware and software comprehensible for Technology Education teachers. Desktop VR systems can be integrated into Technology Education labs for less than $2500 with free, user-friendly software, inexpensive tracking devices, and goggles designed for game applications. The hardware, software, and concepts discussed in this article help achieve this goal with a minimal investment of time and resources.

References


CHAPTER 3. CONCEPT ATTAINMENT IN 8TH GRADE PHYSICAL SCIENCE: MODELS AND VIRTUAL REALITY

A manuscript intended for submission to Presence

Sylvia Tiala

Abstract

Is it possible to use students’ interest in simulations, VR and computer games to increase academic achievement in school-based educational scenarios? Traditional, model and virtual reality teaching environments were used to teach concepts related to simple machines to eighteen volunteers from a rural, Midwestern, eighth-grade science class. No statistically significant difference in knowledge acquisition, as measured by a written test, was found between the different teaching environments. Nonparametric tests did show a statistically significant concept gain, as measured by scores from concept maps, for students in the model and VR environments.

Introduction

Can computer-based learning tools such as electronic games, simulations and virtual reality increase academic achievement in school-based classrooms? Computer-based learning tools include computer animation, simulations, electronic games and virtual reality. Computer animations are the least interactive with users able only to start and stop animations (Davies, 2002). Computer simulations which include the machines, devices and processes (Tracey, 1992) to compute representations of situations where users have control of the outcome.

1 Models for this study were provided by Denis V. Dorozhkin, Iowa State University

2 Thanks to R. F. for his efforts with this study.

3 Thanks to the BCSD and administration for their support in completing this project.
(Davies, 2002) include electronic games and virtual reality. Video games, like virtual reality, engage participants in a computer-generated world, allow users to manipulate variables, allow individuals to alter perspectives, observe behavior over time, view events in three dimensions, and provide immediate feedback (Squire, n.d.).

Increasingly K-12 students are using computers as computing power increases and the cost of technology decreases. Seventy percent of children living in the United States between the ages of 3 and 17 have access to computers. Fifty nine percent of these children use home computers to play video games (Child Trends 2003; DeBell & Chapman, 2003) and 70% of today’s college students play video games (Riegle, 2004). Estimates indicate that the gaming industry generates over $30 billion each year worldwide. It is the fastest-growing segment of the United States’ entertainment industry (Novak, 2005).

It may be possible to use students’ interest in simulations, VR and computer games to increase academic achievement in school-based educational scenarios. Din and Caleo (2000) and Rosas et al. (2003) found a positive increase in student motivation and classroom dynamics when educational video games were used. Chee (2001) describes how words and concepts at the language level are rooted in experience. This concrete experience provides the needed base for reflective observation and abstract conceptualization as described by Kolb’s learning theory. Chee (2001) successfully incorporated experiential learning and dialogue between learners into the classroom using battleship and vacuum chamber simulations. Incorporating simulations and VR applications into educational settings achieves two goals. First, VR applications allow learners to intuitively understand how objects function and behave (Salzman, Loftin and Dede, 1996; Moshell, Hughes, and Loftin, 1999; Chee, 2001). Second, VR applications and simulations may lay the foundation for
deeper learning and conceptual change for both the teacher and the student. This is accomplished by providing common experiences students and teachers reference to within a conversational framework of dialog, reflection, and instructional activities (Chee, 2001).

The goal of this study was to determine if a desktop virtual reality system (Ausburn and Ausburn, 2004) could be used to increase the academic achievement in volunteers from a rural, Midwestern, eighth-grade science class. Mockups or VR environments are indicated in situations where traditional models don’t convey concepts adequately (Shulman, 1999). Developing models that were similar to real-world scenarios for concept transfer (Kozak, Hancock, Arthur and Chrysler, 1993) while enhancing student learning (Moshell, Hughes, and Loftin 1999; Davies, 2002) and providing enough time in computer-generated teaching environments to impact learning (Salzman, Loftin and Dede, 1996; Rosas et. al, 2003) were factors considered in designing this study. Another consideration included educational utility, demonstrating that one method of instruction is better/worse than another for concept attainment. Usability, students’ ability to interact with educational models precluded the use of a data glove which can be difficult to manipulate. Learning, students’ ability to obtain science concepts and relate these concepts to other problems was also considered (Salzman, Loftin and Dede, 1995). Reflection and teacher-learner interaction were included as this may be a critical element in individuals’ concept attainment when exposed to computer-generated learning environments (Chee, 2001; Ohlsson, Moher, and Johnson, 2000). Although the models used in the study were designed to convey concepts and keep students’ attention (using feedback and interactivity) they stopped short of an educational game or “edutainment” (Rosas et. al, 2003, Novak, 2005).
Method

Participants

Eighteen eighth grade science students volunteered for this study. Six males and twelve females ranged in ages from thirteen (2) to fourteen (16) years of age. Three of the subjects in the study attended Level 1 resource programs. Three students received free lunch; three students received reduced lunch prices while twelve students paid full price for lunch. The six students needing corrective lenses wore them in this study. All student participants were offered five dollars for approximately 1 hour of their time. A pizza party was given to all 8th grade students in the participating teacher’s, Mr. R’s class upon completion of the study.

Mr. R was the instructor for both ninth and eighth grade sciences classes examined in this study. Thus the instructor variable in all of the data collected was consistently obtained from the same teacher. Data from 2004 tests indicated that 27.4% of Mr. R’s 9th grade Physical Science students obtained a score of less than 50% on a test related to simple machines. Forty-eight percent of the 9th grade Physical Science students did not meet proficiency levels by scoring less than 60% on a similar Physical Science Test.

Environments

Three parallel environments (traditional, model and VR) were constructed for studying levers. A stick drawn on a piece of paper was used in conjunction with paper cutouts, manipulatives, in the traditional environment as shown in Figure 3.1. Paper triangles were used to represent fulcrums while squares were used to represent masses.
Figure 3.1. Levers in traditional (a), model (b), and VR (c) environments

Students moved these paper manipulatives as the researcher asked weight-and-balance related questions. Students in the model environment worked with a painted dowel rod balancing on an actual fulcrum. Washers used as masses were moved along the dowel rod as students answered the same weight-and-balance questions posed to students in the traditional group. A three-dimensional computer model of a lever was generated from Open GL geometric primitives on a desktop computer for the VR group using Iowa State University's VR Juggler 1.07 (available from http://www.vrjuggler.org). Linux, Fedora™

Figure 3.2. Wheels and axles in traditional (a), model (b) and VR (c) environments
Core 3 (available from http://fedora.redhat.com), running on a 1.6 GHz processor with a NVIDIA Quadro™ 4 700 XGL graphics card, provided stereo vision to students who were wearing iO Display Systems' i-glasses PC. The VR group used a menu toggled by computer keys to manipulate levers in the VR environment as they answered weight-and-balance questions. Similar environments were modeled and used to explore concepts related to wheels and axles as shown in Figure 3.2.

Evaluation Instruments

Two evaluation instruments were used in this study. Student participants used identification numbers on the evaluation instruments and scoring criteria were established before assessments were graded to help remove bias from study results. The first evaluation instrument was Mr. R's teacher-generated test which had been used for several years at the ninth-grade level. This measures rote learning. It indicates information that is stored in long term memory but that is not integrated with existing relevant knowledge (Cañas et. al, 1991). Figure 3.3 shows the drawing that accompanied Mr. R's teacher-generated test. It included questions such as:

![Figure 3.3 Sketches accompanying Mr. R's written test questions](image)

*Figure 3.3 Sketches accompanying Mr. R’s written test questions*
a) in the drawing C, what is the efficiency of this machine? or b) it takes 250 Newtons of force to turn the wheels on a tractor (drawing D), how much force does a farmer have to use to turn the wheel?

Correlations (2 tailed) between students' post test scores on Mr. R's teacher-generated test and national standardized Science (Spearman's rho = .481, $r^2 = .2312$), Math (Spearman's rho = .645, $r^2 = .4160$) and Reading (Spearman's rho = .629, $r^2 = .3956$) scores from *The Iowa Test of Educational Development* (Riverside Publishing, 2001) reached significance respectively at the .05, .01 and .01 level.

The second assessment instrument used in the study was a concept map generated by the researcher and shown in Figure 3.4. Students in Mr. R's class were familiar with mapping concepts within the context of their classroom. Concept maps include terms within

![Concept map comparing levers to wheels and axles](image)

*Figure 3.4. Concept map comparing levers to wheels and axles*
boxes that indicate a connection between ideas. They are distinct from assessments measuring rote knowledge in that concept maps relate new knowledge to learner's relevant prior knowledge. Concept maps organize ideas into a conceptual structure (Novak, J. D. n.d.; Cañas et al., 1991) and involve processing information in sensory memory, working memory, short term memory and long term memory (Cañas et al., 1991). The concept map used in this study asked students to indicate the relationship between levers, wheels and axles, as shown in Figure 3.4.

Correlations (2-tailed) were significant at the .05 level for students' written post test scores and concept map scores (Spearman's rho = .502, $r^2 = .2520$), for concept map scores and standardized Science scores (Spearman’s rho = .503, $r^2 = .2530$) and for concept map scores and standardized Reading scores (Spearman’s rho = .497, $r^2 = .2470$).

**Procedure**

This study used a pre-test, post-test with a control group design. Students in the *traditional* group served as the control while the experimental groups included students in the *model* and *VR* environments. Student volunteers were separated into a "high scoring" group and a "low scoring" based on previous classroom tests on simple machines. Microsoft’s Excel® random number generator was used to assign students to a *traditional* group, a *model* group or a *VR* group. An attempt was made to generate as much of a stratified random sample as the study constraints would allow.

All 8th graders in Mr. R’s class participated in pre-testing which included the written pre-test and the concept map. Six students assigned to the *traditional* group served as the control group. Each student assigned to this group spent approximately one hour with this researcher learning about levers, wheels and axles while using paper manipulatives and
drawings on paper. Upon completion of the instruction students were asked a series of questions in the format of a structured interview. Further instruction was provided for students who were not able to answer questions such as, "How do you find output work on a lever". Students were also asked to fill out the same concept map they had received as a pre-test item in Mr. R's class.

Six students assigned to the model group served as the experimental group having access to accurate models representing levers, wheels, and axles. Each student assigned to this group spent approximately one hour with this researcher learning about levers, wheels and axles while using models made from dowel rods, plumbing fixtures and metal washers. Upon completion of the instruction students participated in a structured interview, received further instruction if needed and filled out concept map given as a pre-test item.

Six students assigned to the VR group served as the second experimental group. Each student assigned to this group spent approximately one hour with this researcher learning about levers, wheels and axles while using computer-generated levers, wheels and axles displayed in three dimensions in a head-mounted-display. The same exit procedure used for the traditional and model groups was used for the VR group.

Upon completion of this researcher's intervention with the 18 volunteers, Mr. R provided instruction on levers, wheels and axles to his entire 8th grade class. All 8th graders then took the written post test and filled out a final concept map in this test-retest scenario. The time from pre-test to final post-test was approximately 2 weeks. Instruction with the researcher occurred during mornings, evenings and weekends over a period of seven days.
Results

Data analysis focused first on the rote knowledge acquired by students as indicated by scores on Mr. R’s written test. The nonparametric Kruskal-Wallis H test indicated there was not a statistically significant difference in pre-test or post-test scores between students exposed to either the traditional, model or VR treatments. A Wilcoxon Signed Rank Test was used to evaluate rote knowledge gains for each of the traditional, model or VR treatments. There was a statistically significant gain at the .05 level for all study participants from pretest to post-test condition on Mr. R’s written test as shown in Table 3.1.

Table 3.1. Rote knowledge acquired in each learning environment.

<table>
<thead>
<tr>
<th>Time period</th>
<th>N</th>
<th>Mean Rank</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1 (Pre-test)</td>
<td>6</td>
<td>4.67</td>
<td>1.722</td>
</tr>
<tr>
<td>Time 2 (Post-test)</td>
<td>6</td>
<td>15.33</td>
<td>4.155</td>
</tr>
<tr>
<td></td>
<td></td>
<td>z = 2.201</td>
<td>Asymp. Sig. (2 - tailed) = .028*</td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1 (Pre-test)</td>
<td>6</td>
<td>4.08</td>
<td>2.973</td>
</tr>
<tr>
<td>Time 2 (Post-test)</td>
<td>6</td>
<td>14.00</td>
<td>5.718</td>
</tr>
<tr>
<td></td>
<td></td>
<td>z = 2.201</td>
<td>Asymp. Sig. (2 - tailed) = .028*</td>
</tr>
<tr>
<td>VR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1 (Pre-test)</td>
<td>6</td>
<td>5.17</td>
<td>1.722</td>
</tr>
<tr>
<td>Time 2 (Post-test)</td>
<td>6</td>
<td>16.83</td>
<td>4.355</td>
</tr>
<tr>
<td></td>
<td></td>
<td>z = 2.201</td>
<td>Asymp. Sig. (2 - tailed) = .027*</td>
</tr>
</tbody>
</table>

* Significant at the .05 level

There was a difference in group performance for students enrolled in this study when compared to students who took the same test in previous years. Overall 22% (4) of this study’s participants scored less than 50% which is comparable to scores from Mr. R’s former classes that had a 27.4% failure rate. However, only 27.8% (5) students didn’t meet a 60% proficiency rate in this study. This compares with data from Mr. R’s past tests.
showing that 48% of students did not meet a 60% proficiency level. Nonparametric
Kruskal-Wallis H tests indicated that there was not a statistically significant difference in the
amount of time students from each group spent in the teaching-learning environment (4
cases missing). There was not a statistically significant difference in the amount of time
students from each group spent in the final exit interview sessions. A Spearman’s Rank
Order Correlation showed no statistically significant correlation between students’ written
post-test scores and time in a teaching environment. A negative correlation reaching
significance at the .10 level (Spearman’s rho = -.464, n = 18, 2-tailed Sig. = .052, \( r^2 = .21 \))
exists between post-test scores on the final written exam and the interview time. The
teacher-researcher spent more time reviewing concepts with students who appeared to have
trouble answering exit interview questions. The students who spent the most time with the
teacher-researcher scored worse than students who spent less time with the teacher-
researcher on the final written test.

Data analysis then focused on conceptual knowledge students gained as indicated by
concept map scores. There was a statistically significant gain at the .05 level for all study
participants from pretest to post-test condition (Wilcoxon Signed Rank z = -2.906, Assymp.
Sig. (2 tailed) > .004) for concept map scores. The nonparametric Kruskal-Wallis H test
indicated there was not a statistically significant difference in either pre-test concept map
scores or post-test concept map scores between students exposed to either the traditional,
model or VR treatments. Twenty eight percent (5) of the students in the study had less than
proficient scores on the concept map post test. Three students not meeting the 60%
proficiency level on the concept map were from the traditional group. One student from the
model group and one student from the VR group did not meet proficiency on the concept
map post-test. A Spearman's Rank Order Correlation showed no statistically significant correlation between students' post-test scores on concept maps and time in a teaching environment. A negative correlation reaching significance (Spearman's rho = -.803, n = 18, 2-tailed Sig. = less than .0005) exists between post-test scores on the concept map post-test and interview time. Students who best articulated concepts related to levers, wheels, and axles spent less time with the teacher-researcher in the exit interview and scored higher on the final written test. The Friedman test was run individually on the traditional, model, and VR groups to assess concept attainment. Table 1 shows that the Friedman test did not indicate a statistically significant difference in concept attainment scores from the pretest to post test (Chi-Square = .381, df = 2, Asymp. Sig. =.827) for students in the traditional manipulative group as measured by the concept map. There was a statistically significant gain in concept attainment at the .05 level for students in the model group (Chi-Square = 6.636, df = 2, Asymp. Sig. = .036) and for students in the VR group (Chi-Square = 6.125, df = 2, Asymp. Sig. = .047).

Discussion

It should be stressed that the results from this study can not be generalized to other groups. The study took place within constraints of a real school setting. Internal validity may have been impacted by student volunteers who were motivated to learn. Small samples sizes and skewed data distributions indicated the use of nonparametric statistics.

Within these real-life constraints, this study showed that students performed well in all learning environments. Students in each of the traditional, model, and VR groups made statistically significant gains from pre-test to post-test on Mr. R's written test. Traditional teaching methods may be the most efficient way of conveying rote knowledge to students.
The fact that more students in this study reached proficiency levels than their counterparts from previous years may be attributed to the exit interview stage of the study as well as the teaching method. The better students scored on the post-test, the less time they had spent in the exit interview. The conclusion one hopes to reach is that experienced teacher-researchers are able to identify which students need help grasping information and which students have reached proficiency in grasping content. There is no statistical evidence, (as shown in the results section), that training environments made a difference in the amount of rote knowledge students' obtained. Two of the students not reaching proficiency levels were instructed using the traditional environment. Two students not reaching proficiency levels were instructed in the model environment. One student not reaching the proficiency level was instructed in the VR environment.

This study did support the idea that models, simulations and VR can help students intuitively understand their world. Three of the five students who did not achieve proficiency on the written assessment were trained in the traditional environment. Table 3.2 shows that students in both the model and VR teaching environments gained in concept attainment at a statistically significant level while students exposed to the traditional learning environment did not make statistically significant gain. It should be noted that the variance of the post-test concept map scores decreased over time for students in the traditional and model environments but increased for students in the VR environment. More research is needed to identify if this is a significant issue in different learning environments.

Within this study all students acquired rote knowledge to a statistically significant degree in all three learning environments. Students who did not achieve proficiency at rote learning were evenly distributed in each of the traditional, model and VR group. Students in
Table 3.2. Concept map scores over time.

<table>
<thead>
<tr>
<th>Time period</th>
<th>N</th>
<th>Mean Rank</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traditional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1 (Pre-test)</td>
<td>6</td>
<td>1.83</td>
<td>3.67</td>
<td>2.25</td>
</tr>
<tr>
<td>Time 2 (Post-intervention)</td>
<td>6</td>
<td>2.17</td>
<td>4.5</td>
<td>2.94</td>
</tr>
<tr>
<td>Time 3 (Post-test)</td>
<td>6</td>
<td>2.00</td>
<td>4.83</td>
<td>0.98</td>
</tr>
<tr>
<td>Chi-Square = .381</td>
<td></td>
<td>Asymp. Sig. = .827</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1 (Pre-test)</td>
<td>6</td>
<td>1.33</td>
<td>3.00</td>
<td>2.97</td>
</tr>
<tr>
<td>Time 2 (Post-intervention)</td>
<td>6</td>
<td>1.92</td>
<td>4.67</td>
<td>2.16</td>
</tr>
<tr>
<td>Time 3 (Post-test)</td>
<td>6</td>
<td>2.75</td>
<td>6.83</td>
<td>1.83</td>
</tr>
<tr>
<td>Chi-Square = 6.636</td>
<td></td>
<td>Asymp. Sig. = .036*</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1 (Pre-test)</td>
<td>6</td>
<td>1.33</td>
<td>4.67</td>
<td>1.37</td>
</tr>
<tr>
<td>Time 2 (Post-intervention)</td>
<td>6</td>
<td>2.25</td>
<td>5.83</td>
<td>1.60</td>
</tr>
<tr>
<td>Time 3 (Post-test)</td>
<td>6</td>
<td>2.42</td>
<td>6.17</td>
<td>1.83</td>
</tr>
<tr>
<td>Chi-Square = 6.125</td>
<td></td>
<td>Asymp. Sig. = .047*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at the .05 level

The model and VR environments did better than their traditional counterparts at integrating past knowledge with new concepts as indicated by the concept map. Learning environments using models or VR may help student learn better. The introduction of model and VR environments helps explain why more students reached proficiency levels on this year’s test than have reached proficiency on previous years’ test.

Further research is needed into the kinds of virtual reality environments that impact knowledge acquisition and concept attainment. It is important to have a large enough study population to tease apart the effects of the teaching environment from the impact of the exit interview on students’ knowledge acquisition and concept attainment. Human-computer interfaces that maximize usability and learning need exploration. The amount of time needed for a computer-generated teaching environment to be effective should be
determined. Attention should be directed toward the interaction of socio-economic status, learning disabilities, assessments of rote learning and concept attainment. Four of the five students not reaching proficiency levels on the written test were either students with identified learning disabilities or who came from low socio-economic backgrounds. This pattern changed for performance on concept maps. Three students not reaching proficiency levels on the concept map were from high socio-economic backgrounds, had no identified learning disabilities but were trained in the traditional environment. Is it the students’ background that made a difference or does an individual’s learning style impact achievement?

This research cannot be generalized to other populations but it provides direction for further studies. Virtual environments have been show to motivate students (Din and Caleo, 2000; Rosas et al., 2003). More research is needed to determine how to design computer-generated environments for the greatest positive impact on student achievement.

References


CHAPTER 4. METHODS AND MODELS FOR CONCEPT ATTAINMENT IN 8TH GRADE SCIENCE

A manuscript intended for submission to Computers in Education Journal

Sylvia Tiala $^{1,2,3}$

Abstract

Cognitive theories of multimedia learning, dual coding theory and levels of processing theory were examined in relation to the teaching-learning environment. Students in all three environments showed significant gains from pretest to post-test supporting dual-coding theory and levels of processing theory. Lower test scores for students in the graphics group can be accounted for by the amount of skill needed to mentally construct three-dimensional images from two-dimensional graphics. Robust personal models conflicting with the information being presented and non-relevance in examples were posited as explanations for no correlation between perceived fun and actual performance.

Introduction

Do games, simulations and virtual reality help Kindergarten through twelfth grade students understand scientific concepts better? Are there cognitive theories that help explain why games, simulations and virtual reality should be used in the classroom? Trindade and Fiolhais (2000), Wang and Hu (2000), Song, Han and Lee (2000) describe

---

$^1$ Models for this study were provided by Denis V. Dorozhkin, Iowa State University

$^2$ Thanks to R. F. for his efforts with this study.

$^3$ Thanks to the BCSD and administration for their support in completing this project.
how virtual reality (VR) is used to teach geosciences, phases of matter and geometry. Din and Caleo (2000); Rosas et al. (2003); Robertson and Good (2005) show that student motivation, positive classroom dynamics and self-esteem increase when educational video games are used as teaching tools in formal classroom settings. Salzman, Loftin and Dede (1996), Moshell, Hughes and Loftin (1999) and Chee (2001) argue that virtual reality applications allow learners to intuitively understand how objects function and behave. Chee successfully incorporated experiential learning and dialogue between learners into the classroom using battleship and vacuum chamber simulations. Ford, Frederickson and Martin (2000) argue that dynamic computer simulations require less skill to interpret than traditional static graphics. Ford, Frederickson and Martin also argue that students' past experiences are robust and individuals may not interpret computer-generated models as the instructional designers intended. Ohlsson, Moher and Johnson (2000) used a displacement scenario to help second graders obtain deep cognitive change. At the same time Mayer and Moreno (1998) argue that the effective use of instructional technologies (including simulation, gaming and virtual reality) that is grounded in research-based theory with a learner-centered approach will alleviate a pattern of large-scale implementation of new technologies that eventually fail. Davies (2002) cites studies suggesting that computer-based learning tools used incorrectly may have a negative impact on learning. Moreno and Mayer (n.d.) also find that instruction using given media does not matter if the methods promoting cognitive processing foster student learning with the technology used.

Studies using games, simulations and VR models for instruction are based on the principles of Rogers' theory of experiential learning and Lave's situated learning theory.
Students construct their own mental models of the world (Moshell and Hughes, 1999) through relevant experiences that link prior knowledge to new information (Rossner-Merrill, Parker, Mamchur and Chu, 1998). Learners are active participants in the teaching-learning process, have control of their environment, learn within a social context and participate in self-evaluation (Kearsley, 1994-2003; Rossner-Merrill et al, 1998; Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). The implication that may be made from recent studies using games, simulations and VR is that students who are more engaged in their own learning are more motivated and perhaps have more fun while learning (Bierman, 2005; Barab et al. 2005).

Research relevant to Pavio’s dual-coding theory and Craik and Lockhart’s level of processing theory may be applied to learning within gaming, simulation and virtual reality environments. Information is easier to remember when it is presented both verbally (text or auditory) and graphically. Information that is rehearsed with cueing materials and verbal processes facilitates better recall (ChanLin, 1994). Chee’s (2001) study using computer simulations integrated with student dialog is an example. Moreno and Mayer (2000, p. 1-2) developed a cognitive theory of multimedia learning that draws on “Pavio’s ... dual coding theory, Baddeley’s ... model of working memory, (and) Sweller’s ... cognitive load theory”. Their six principles: split-attention, modality, redundancy, spatial contiguity, temporal contiguity, and coherence can be applied to simulation, gaming and virtual reality learning environments (Moreno and Mayer, 2000).

The goal of this study was to apply cognitive theories of multimedia learning (Moreno and Mayer, 2000), dual coding theory and levels of processing theory in a realistic environment that used desktop VR (Ausburn and Ausburn, 2004) as a teaching
method. This study also examined students’ perception of a desktop virtual reality system (Ausburn and Ausburn, 2004) as a motivating learning environment. Lever, wheel and axle models used in the study were designed to convey concepts and keep students’ attention (using feedback and interactivity) but they stopped short of an educational game or “edutainment” (Rosas et al., 2003; Marinell and Pausch, 2004; Novak, 2005).

**Method**

**Participants**

Six male and twelve female eighth grade science students at a rural, Midwest high school volunteered for this study. Students ranged in age from thirteen (2) to fourteen (16). Three of the subjects in the study attended Level 1 resource programs. Six students received free or reduced lunch prices while twelve students paid full price for lunch. The six students needing corrective lenses wore them in this study. All student participants were offered $5 for approximately 1 hour of their time.

Data collected for this study was obtained from Mr. R. who taught both the ninth and eighth grade sciences courses examined in this study. Thus the instructor variable in all of the data collected was consistently obtained from the same teacher. Data from 2004 tests indicated that forty-eight percent of the 9th grade Physical Science students did not meet proficiency levels by scoring less than 60% on a Physical Science Test relating to levers, wheels and axles. During an interview Mr. R indicated that faucets on the sinks in the science labs did not serve as adequate models for students to grasp the concept of wheels and axles. Models made of wooden sticks failed to convey the mathematical relationship between force and distance as it relates to levers and
mechanical advantage. Additionally, teeter-totters, the preferred model used for discussing levers had been removed from this town’s playground over five years previously. Mr. R’s experiences reflect the experiences of other teachers who find current models for conveying abstract concepts lacking (Song, Han and Lee, 2000; Wang and Hu, 2000, Trindade and Fiolhais, 2000, Chee, 2001).

**Environments**

Three parallel environments (*graphic, model and VR*) were constructed for studying student motivation. A lever drawn on a piece of paper was used in conjunction with paper cutouts (manipulatives) in a two-dimensional *graphic* environment as shown in Figure 4.1a. Paper triangles (fulcrums) and paper squares (masses) were moved along the drawn lever as the researcher asked weight-and-balance related questions. The graphic environment presented data both verbally and graphically to enable dual-coding. However, as Ford, Frederickson and Martin (2000) argue a high level of representational competence is needed to envision this model in three dimensions. This two-dimensional representation may violate Moreno and Mayer’s (2000) split-attention principle.

Although students are receiving information through a verbal and graphics channel,
there is a lot of attention needed to convert the two-dimensional graphic into a three-dimensional mental model. If students are visually processing data, the verbal cues within the learning environment may be ignored.

Students in the model environment worked with a lever made from a painted dowel rod balancing on a fulcrum as shown in Figure 4.1b. Washers used as masses were moved along the dowel rod as students answered the same weight-and-balance questions posed to students in the graphic group. The model environment presented data both verbally and graphically to enable dual-coding. Direct-experience within the environment should not have split students’ attention between verbal and graphic channels and should not have required a high degree of competence converting the perceived objects into three dimensions. Students should be able to pay attention to both verbal and visual cues within this instructional environment.

A three-dimensional computer model of a lever was generated from Open GL geometric primitives on a desktop computer for the VR group using Iowa State University’s VR Juggler 1.07 (available from http://www.vrjuggler.org). Linux, Fedora™ Core 3 (available from http://fedora.redhat.com), running on a 1.6 GHz processor with a NVIDIA Quadro™ 4 700 XGL graphics card, provided stereo vision to students who were wearing iO Display Systems’ i-glasses PC. The VR group used a menu toggled by computer keys to manipulate levers in the VR environment as they answered weight-and-balance questions. The VR environment presented data both verbally (written and spoken) and graphically to enable dual-coding. The verbal presentations were sequential and are believed to affect student learning in a positive manner as described by Moreno and Mayer’s (2000) redundancy principle. Having the
navigation menu close to the animation followed Moreno and Mayer’s (2000) spatial contiguity principle. Students manipulated the lever, watched the animation, and received feedback in small chunks at close intervals. No sound effects, haptic feedback or other extraneous material were included in the VR world. This followed Moreno and Mayer’s (2000) temporal contiguity and coherence principles of instruction in multimedia learning environments. Some degree of representational competence (Ford, Frederickson and Martin, 2000) may be needed in the VR environment. Students’ skills at navigating within the computer-generated environment and viewing the model from different vantage points may have impacted their ability to visualize the objects in three dimensions. Navigational issues may also violate Moreno and Mayer’s (2000) split-attention principle. Visual cues conflict as students are distracted from learning content as they attend to navigational issues within the VR environment.

Three similar models were developed for exploring concept attainment for wheels and axles as shown in Figure 4.2.

![Figure 4.2. Wheels and axles in traditional (a), model (b) and VR (c) environment](image-url)
Evaluation Instruments

Mr. R's teacher-generated, written test and a concept map generated by the researcher were the evaluation instruments used in this study. Student participants used identification numbers on the evaluation instruments and scoring criteria were established before assessments were graded to help remove bias from study results. Figure 3 shows the drawing that accompanied Mr. R's teacher-generated test. It includes questions such as: a) in the drawing C, what is the efficiency of this machine? or b) it takes 250 Newtons of force to turn the wheels on a tractor (drawing D). How much force does a farmer have to use to turn the wheel? Correlations (2 tailed) between students' post test scores on Mr. R's teacher-generated test and national standardized Science (Spearman's rho = .481, $r^2 = .2312$), Math (Spearman's rho = .645, $r^2 = .4160$) and Reading (Spearman's rho = .629, $r^2 = .3956$) scores from The Iowa Test of Educational Development reached significance respectively at the .05, .01 and .01 level.

![Figure 3](image)

**Figure 4.3.** Sketches accompanying Mr. R's written test questions

The researcher's concept map, shown in Figure 4.3, asked students to indicate the relationship between lever, wheels and axles. Students in Mr. R's class had used
concept maps in the classroom and were familiar with their use. Correlations (2-tailed) were significant at the .05 level for students' written post test scores and concept map scores (Spearman's rho = .502, $r^2 = .2520$), for concept map scores and standardized Science scores (Spearman's rho = .503, $r^2 = .2530$) and for concept map scores and standardized Reading scores (Spearman's rho = .497, $r^2 = .2470$).

**Figure 4.3 Concept map comparing levers to wheels and axles**

During the final exit interview students ranked how much fun they had and how much they had learned during one-one-one instruction. The responses, ranked on a scale of one to ten, were used to examine the hypothesis that students learning in VR environments would have more fun and thus be motivated to learn more.

**Procedure**

This study used a pre-test, post-test with a control group design. Students in the *graphic* group served as the control while the experimental groups included students in
the model and VR environments. Student volunteers were separated into a "high scoring" group and a "low scoring" based on previous classroom tests on simple machines. Microsoft's Excel ® random number generator was used to assign students to a graphic group a model group or a VR group. An attempt was made to generate as much of a stratified random sample as the study constraints would allow.

All 8th graders in Mr. R's class participated in pre-testing which included the written pre-test and the concept map. Six students assigned to the graphic group served as the control group. Students assigned to this group spent approximately one hour of time receiving instruction and rehearsal time with the researcher learning about levers, wheels and axles. Paper manipulatives and drawings on paper visual cues for the learners. Student-researcher dialog provided verbal cues for the learner. Upon completion of the instruction students were asked a series of questions in the format of a structured interview. Further rehearsal was provided for students who were not able to answer questions such as, "How do you find output work on a lever?". Students ended the individualized instruction by completing a structured exit interview and the same concept map they had received as a pre-test item in Mr. R's class.

Six students assigned to the model group served as the experimental group having access to accurate models representing levers, wheels, and axles. Students assigned to this group spent approximately one hour of instruction and rehearsal time learning about levers, wheels and axles. Models made from dowel rods, plumbing fixtures and metal washers served as visual cues while verbal cues were provided within a conversational framework. Further rehearsal and instruction was given when needed.
Students ended the individualized instruction by completing the same structured exit interview and concept map indicated in the graphic group.

Six students assigned to the VR group served as the second experimental group. Computer-generated models of levers, wheels and axles provided both textual (verbal) and visual cues during approximately one hour of instruction and rehearsal. Student-researcher dialog provided additional verbal cueing for the students during instruction and indicated when additional rehearsal was needed. Students ended the individualized instructional environment by completing a structured exit interview and the concept map used for other groups.

Upon completion of this researcher's intervention with the 18 volunteers, Mr. R provided instruction regarding levers, wheels and axles to his entire 8th grade class. All 8th graders then took the written post test and filled out a final concept map in this test-retest scenario. The time from pretest to final post test was approximately 2 weeks with instruction outside of class occurring over seven days.

**Results**

Were students exposed to the virtual reality learning environment more motivated to learn than their counterparts exposed to the graphic or model learning environment? Did the amount of perceived fun impact students learning? The nonparametric Kruskal-Wallis H test indicated there was not a statistically significant difference in either pre-test or post-test scores between students exposed to either the graphic, model or VR treatments. Students ranked the VR (5.33) environment the least fun with real models being the most fun (12.25). A two tailed Kruskal-Wallis H test indicates that this difference reached statistical significance at the .10 level (Chi-Square
= 5.771, df = 2, Asymp. Sig. = .056) as shown in Table 4.1. Students indicated that they learned slightly less in the VR (8.58) environment than they did in either the Model (8.58) or the Graphic (10) environment. There was no statistically significant difference in the amount of perceived learning between the three teaching environments.

**Table 4.1. Kruskal-Wallis H Test Training method and final scores**

<table>
<thead>
<tr>
<th></th>
<th>#</th>
<th>Written Post Test Rank</th>
<th>Concept Map Post Test Rank</th>
<th>Fun Rank</th>
<th>Learn Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphic</td>
<td>6</td>
<td>8.5</td>
<td>6.17</td>
<td>10.92</td>
<td>10</td>
</tr>
<tr>
<td>Model</td>
<td>6</td>
<td>8.5</td>
<td>12</td>
<td>12.25</td>
<td>9.92</td>
</tr>
<tr>
<td>VR</td>
<td>6</td>
<td>11.5</td>
<td>10.33</td>
<td>5.33</td>
<td>8.58</td>
</tr>
<tr>
<td>Chi Square</td>
<td></td>
<td>1.270</td>
<td>4.079</td>
<td>5.771</td>
<td>.274</td>
</tr>
<tr>
<td>Degree of Freedom</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Asymp Sig.</td>
<td></td>
<td>.530</td>
<td>.130</td>
<td>.056</td>
<td>.872</td>
</tr>
</tbody>
</table>

Achievement, indicated by written post-test scores, indicates no statistical difference between students exposed to the virtual reality training method and their counterparts in either the traditional or the model environments. Students ranked the two-dimensional learning model the highest for perceived learning and the second most fun of the learning environments. The written assessments indicate that this environment was the least effective of the teaching-learning environments. The model environment was
ranked high for perceived learning and the most fun. Scores on the concept maps were the highest for the *model* group and were comparable with the two-dimensional *graphic* group for written test scores. The *VR* group indicated that their learning environment was the least fun and the least effective yet this group had the highest scores on the written test and scored well on the concept map. Spearman’s rank order correlation (2-tailed) showed no significant correlation between the amount of perceived learning and the written test score (-.018), perceived fun and the concept map score (-.146), perceived learning and the concept map score (.030) or perceived fun and the concept map score (-.118). Rosas et al.’s (2003) and Robertson and Good’s (2005) results that computer-generated learning environments provide motivation were not supported with this group of students. Bierman (2005) and Barab et al.’s idea that students find computer-generated learning environments fun did not hold true for this group of students.

Chee (2001) argues that experiential learning and teacher-student dialog helps students learn with deep understanding. Ohlsson, Moher and Johnson (2000) assume that neither experience nor communication will change robust but incorrect mental models. Seventeen transcripts from students’ exit interviews were examined for indicators regarding individual’s experience with tools and concept attainment. The assumption was that students who work with tools have more correct and robust mental models of simple machines in place that facilitates concept attainment regarding levers, wheels and axles. Students indicating that they used tools a lot to rebuild bicycles, build go-carts or work with pneumatic tools were given an *Expert* ranking. Students indicating they used ordinary tools such as screw drivers, hammers or can openers were given a *Medium* ranking. Students indicating they did not use tools very much were given a *Low* ranking.
Students that did not see the relationship between the fulcrum of a lever and the axle on a wheel, who didn't understand the fulcrum was a pivot point, or who indicated that wheels and axles could change size but levers could not were put into a Didn't Get category. Students who could make some comparisons between input levers, wheels and axles were put into a Simple category. Students who understood that both wheels and axles were levers with the input arm offset from the output arm and who could articulate the similarities and differences were put into an Got It category. The number of students in each category with their assigned training method is indicated in the Table 4.2. There were not enough participants to run a statistical analysis of the interaction of instructional method and tool use. It appears that students that with more experience using tools left the exit interview with the highest number of misconceptions regarding levers, wheels and axles.

Table 4.2. Students' tool use versus concept attainment with simple machines

<table>
<thead>
<tr>
<th></th>
<th>Expert (7 total)</th>
<th>Medium (6 total)</th>
<th>Low (4 total)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Got It</strong></td>
<td>VR - 1</td>
<td>Graphic - 1</td>
<td>VR - 1</td>
</tr>
<tr>
<td>(3 Total)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Simple</strong></td>
<td>Model - 1</td>
<td>Graphic - 2</td>
<td>Model - 1</td>
</tr>
<tr>
<td>(7 Total)</td>
<td>VR - 1</td>
<td></td>
<td>VR - 1</td>
</tr>
<tr>
<td><strong>Didn't Get</strong></td>
<td>Graphic - 1</td>
<td>Graphic - 1</td>
<td>Graphic - 1</td>
</tr>
<tr>
<td>(8 Total)</td>
<td>Model - 2</td>
<td>Model - 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VR - 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

All three of the instructional models used in the study included visual and verbal cueing materials and rehearsed information. Students in all three environments showed significant gains from pretest to post-test supporting dual-coding theory and levels of processing theory. Moreno and Mayer’s (n.d.) theory that the type of instructional media doesn’t matter as long as instructional methods promote cognitive processing is also supported. Lower test scores for students in the graphics group can be accounted for by the amount of skill needed to mentally construct three-dimensional images from two-dimensional graphics thus taking mental processing attention away from processing the necessary verbal information.

Students’ perception of fun and their perceived amount of learning did not correlate with actual performance on the performance assessments in the study. One reason may be that students reported what they thought the researcher wanted to hear. That is, learning should not be perceived as fun. Students were told before the study began that they may be assigned to a virtual reality world. They may have been disappointed that the modeled environment was not a game-like experience. Many of the students brought prior experience and the associated mental models into this study. The lack of fun and lack of perceived learning may be an indication that the robust personal models were conflicting with the information being presented and the questions that were posited. If so a different instructional approach, like the displacement scenario as described by Ohlsson, Moher and Johnson (2000), may be indicated. Students’ lack of perceived fun may also indicate that models used for teaching science concepts are not relevant and are not interesting. It would be interesting to study the perceived
amount of fun and learning indicated if examples relevant to students’ lives (levers from
gaming devices, computer mice, control knobs on stereos, compact disk motors) were
used as examples.

Although this study took place within the constraints of a real school setting and
results can’t be generalized, it lays the foundation for further exploration into cognitive
learning theories related to virtual reality as an instructional tool.

References

technology for teaching and research in industrial teacher education. *Journal of

Barab, Thomas, Dodge, Carteaux, & Tuzun (2005), Making learning fun: Quest atlantis,
a game without guns. *Educational Technology Research & Development* 53(1),
pp. 86-107.


computer graphics design*. (ERIC Document Reproduction Service No. ED
370526).

Proceedings of the International Symposium on Virtual Education 2001, Busan,
South Korea, pp. 43-54. Retrieved January 20, 2004 from


presented at the Annual Conference of the Eastern Educational Research
Association (70th, Clearwater FL, February 16-19, 2000).* (ERIC Document
Reproduction Service No. ED 438905).


CHAPTER 5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Discussion

Students in formal educational settings do not learn in isolation. They interact with peers, teachers, administrators, community members and technology every day. These interactions shape, and are shaped by, theories of cognition, teaching philosophies, learning environments and teacher competency. What is learned and how it is learned is impacted in part by government mandates, access to computer technologies, and personal experiences. Schools are the context where concepts from philosophy, psychology, neuroscience, linguistics and anthropology (Gardner, 1985) merge into practice. The U. S. Department of Education’s (2002) *No Child Left Behind Act* forced educational change that resulted in paradigm shifts. Demonstrating students’ academic achievement is often at odds with implementing the best learner-centered strategies. Achieving the basic skills measured in valid and reliable standardized tests does not help students become the motivated problem-solving team players as called for in national science, technology and math standards (American Association for the Advancement of Sciences, 1993; International Technology Education Association, 2001; National Council of Teachers of Mathematics, 2001-2004).

The *No Child Left Behind Act* (U. S. Department of Education, 2002) has brought debate regarding effective teaching practices to America’s schools. Examining educational practice within this authentic context became the theme for this research project.

The reader should recognize that the articles contained within this paper serve as a starting point for further investigation. The dissertation addressed the three criteria, discussed in the first chapter that will facilitate the implementation of VR in educational settings. The first article *Integrating Virtual Reality in Technology Education Labs*
addresses teachers' computer literacy. Basic concepts related to VR are discussed along with the necessary hardware and software needed for implementation of computer-generated environments.

Another criteria addressed was the collection of data regarding the effectiveness of VR as a teaching tool. The second article, *Concept Attainment in 8th Grade Physical Science*, addressed students' rote knowledge and conceptual gains within an eighth grade science class. It looked at students' learning when subjects were exposed to a virtual reality environment within an authentic educational context. The research was designed to help practicing teachers deliver more effective instruction. Although information from this study cannot be generalized to other populations, it provides a starting point for further research. Data indicate that conceptual learning occurs when real models or virtual reality is used for instruction. This is particularly true for students with learning disabilities and from low socio-economic backgrounds. Thus, information from this research may offer insight into instructional practices at the school where the study occurred. The *Concept Attainment in 8th Grade Physical Science* article may enhance discussions centering on the debate between academic achievements as dictated by government mandates versus best learner-centered practices for students' learning.

Developing a theoretical construct for virtual reality as a teaching-learning medium was another element of bringing VR into the K-12 classroom that was discussed in the introduction. *Methods and Models for Concept Attainment in 8th Grade Science* applied Dual-Coding theory and Levels of Processing theory to student performance in 8th grade science classes. The prior knowledge students in this study brought to the lever, wheel and axle learning environments impacted their learning. Students may not have mentally
processed the instructional models as the designers intended. Examples may not have provided enough motivation. The intent of the article was to demonstrate that various learning theories can be applied to virtual reality environments. Other theories such as Anchored Instruction (Bell, Bareiss, and Beckwith, 1993), Perceptual Symbols theory (Pecher, Zeelenberg and Barsalou, 2003), or Situated Learning theory (Rossner-Merrill, Parker, Mamchur, Chu, 1998), may also predict performance. It is the intent of this author to promote discussion and further exploration of learning theory applied to multimedia instruction in a formal classroom setting. The ultimate goal is to promote paradigm shifts among educators to modern, learner-centered approaches to instruction.

K-12 education institutions will be undergoing major changes in the next few years. Classroom teachers will be impacted as mandates from the No Child Left Behind Act (U. S. Department of Education, 2002) converge with advances in neuroscience and cognition. There is already a demand for better student performance in formal school environments. This pressure is increasing and will force paradigm shifts from old teaching strategies to new instructional methods. More multimedia technologies will be used in conjunction with more learner-centered approaches to education. Virtual reality applications may be a part of this educational reform if it is demonstrated that it is effective at enhancing the teaching-learning process.

**Future Research**

Further investigation is needed to delineate how, why and where virtual reality applications can be used effectively in formal teaching environments. Research already indicates that students in virtual reality environments need feedback and interaction to make learning effective (Chee, 2001; Ohlsson, Moher and Johnson, 2000). What type of feedback
is most effective? How much feedback does an instructor need to provide for students to learn?

Virtual reality provides experiences that help students intuitively understand their world (Salzman, Loftin and Dede 1996; Moshell, Hughes and Loftin, 1999; Chee, 2001). Educational experiences also contribute to students reading achievement (Siegel and Hanson, 1992). Virtual reality may level the instructional playing field by giving all students experience in an environment from which discussion, activities and learning can proceed. The Concept Attainment in 8th Grade Physical Science article gave evidence that models and VR may help student understand their world better. There was an indication that students with learning disabilities or from low socio-economic backgrounds may perform better on test measuring rote learning when they have more experience. More research is indicated to help practicing teachers answer questions related to these results. What types of learners are most positively impacted when learning in VR environments? Is there any interaction between teaching environments and socio-economic status and learning disabilities? To what degree of realism do virtual environments need to be modeled to be effective? Students bring preconceived notions of their world into a learning environment. What techniques should be used to ensure that students learn a concept the way it was intended? Chee (2001) suggests a conversational framework while Ohlsson, Moher and Johnson (2000) suggest a displacement scenario.

Moreno and Mayer (2000) introduced a cognitive theory of multimedia learning that can used in conjunction with Salzman, Loftin and Dede’s (1995) principles of educational utility, usability and learning. Which elements of gaming are necessary to incorporate into virtual reality to promote student motivation without compromising student achievement?
When does instruction in virtual reality cross the line from education to edutainment? Does it matter (Novak, 2005)? Are there cognitive theories in place that will predict student achievement? Can these theories be used to argue for the inclusion of virtual reality in formal K-12 teaching environments? Is it possible to develop valid and reliable assessments applicable to virtual reality that provide evidence of student achievement? Will these assessments have enough research and rigor connected to them to be accepted by government agencies demanding evidence of student performance?

Computer technology and the associated hardware/software are constantly changing. This paper highlighted a small aspect of this technology. Research on the most cost-effective methods of bringing VR to the classroom will be necessary. Attention should also be paid to potential health risks that may be inherent to virtual reality technology. Does long-term exposure to the electrical signals associated with VR pose a health risk? Is an individual's perceptual abilities altered after exposure to a virtual reality? For how long might perception be affected? Will the concepts being modeled pose a danger to students?

The areas mentioned for further research should not be construed as a comprehensive list. It should also be noted that areas for further research will change as the capability of technology changes, as government mandates are implemented, as teachers' paradigms shift, as younger computer-literate teachers enter the workforce and new theories of learning are accepted by practicing teachers.

References


