CONSTRUCTIVISM IN PRACTICE:
THE CASE FOR MEANING-MAKING IN THE

VIRTUAL WORLD

by

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Abstract

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This study compares the educational value of constructivist pedagogy as applied through the design, development and experience of 3-D interactive virtual learning environments to a traditional classroom approach and to a no instruction control. The constructivist treatment provided students with access to their choice of source content, 3-D modeling tools and instruction in virtual world development to assist in developing visual, auditory and interactive signs and symbols in the virtual environment. Traditional instruction included a biology textbook, worksheets and teacher-led discussions. Subjects were 117 7th and 8th grade students in a constructivist classroom studying wetland ecology. Students were separated into four groups each of which were responsible for designing and building a virtual learning environment. Content acquisition and meaning-making was measured by a multiple choice, quantitative pre- and post-test, concept map pre- and post-tests, interviews and a survey. Results indicate significant improvement between both quantitative $F(1, 79) = 97.58$, $p < .001$ and concept map $F(1, 63) = 71.75$, ($p < .001$) pre- and post-test measures. However, treatment analysis yeilded no significant difference between the Constructivist and Traditional treatments, a significant pre-post treatment interaction between Constructivist and the No Instruction control $F(1, 23) = 18.25$, ($p < .001$), and no significant difference between the Traditional and No Instruction approach. Interview data comparing built vs. experienced worlds yeilded a significant difference $F(1, 65) = 14.68$, ($p < .001$). Subsequent research is presented in an Addendum that indicates that virtual world building is both motivational and educationally efficacious.

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I would also like to acknowledge Dr. William Bricken's role in starting me down the path of using virtual reality as an educational tool. Dr. Bricken guest-lectured in one of Dr. Winn's classes on interactive technologies. In one of the most emotional, persuasive presentations I have ever seen, Dr. Bricken managed to convey the power and elegance of using this type of technology to "reintegrate the body, mind and soul in the interest of learning." I was fascinated; enough so to sneak my way into the Human Interface Technology Laboratory on the coat-tails of one of my colleagues, Mr. Jeffrey James, an established Lab associate.

In 1990, Jeff was working on his Master's thesis on boundary mathematics. He kindly offered to share his desk and his computer with me. Pretty soon, Dr. Furness just assumed that I was on a project, which I quickly made into a reality. By the time he realized how cagily I'd entered his Lab, it was too late. I became a Research Associate the following summer, and am greatly indebted to Dr. Furness for his willingness to provide financial and professional support for five years of my doctoral program.

Last but not least, I would like to acknowledge Dr. Chris Byrne. Chris and I worked together near the beginning of the Lab's forays into education, and she is to this day one of my favorite research and development mavens. The Brickens started the educational program, but Chris and I took it to the next level. She ran the Pacific Science Center project, in which we provided virtual world building experience to summer Science Center Camp participants. I was lucky enough to be her assistant during that incredibly long summer. She is now in R&D at Phillips Laboratories, developing educational environments, and conducting research. I thank her deeply for the female ‘grounding’ she provided in a Lab full of (male) engineers. It made all the difference in the world.

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DEDICATION

The author wishes to dedicate this dissertation to Allan and Inger Osberg; staunch supporters, inveterate slave drivers and the most hopeful pair of people you'd ever want to meet. I wouldn't have been as likely to have made it this far without them, and my gratitude and affection run deep.

INTRODUCTION

Children use symbols and relationships between symbols to make meaning of their environment, experiences and interactions. The learning theory that describes the process of creating knowledge from these symbols is known as *constructivism*.

This learning theory postulates that an individual constructs their unique understanding of the world by experiencing, evaluating and incorporating their interpretations into their personal world view. Constructivist learning is active rather than passive; learner-centered rather than teacher-directed.

With advances in visual and interactive technologies such as 3-D interactive computer environments, the process of knowledge construction and meaning making from a visual, auditory and kinesthetic perspective can be more fully explored. By creating their own environments, students can develop their own set of objects, relationships and behaviors that are meaningful to them, and that can be shared and experienced through full-body interaction.

This study was conducted to discover how different learning approaches affect the meaning-making process. Specifically, it was designed to discover if active learning based on constructivist practices would prove to be more educationally efficacious than passive, teacher-led instruction. By providing students with 3-D design tools and real-time technology that facilitated interactive, kinesthetic, visual and auditory learning, it was believed that the meaning-making process would be enhanced, leading to more complex knowledge constructions.

This dissertation documents the use of 3-D interactive environments as a meaning-making tool, exploring the educational efficacy of both the design and experience of knowledge constructions.

CHAPTER 1: RESEARCH PROBLEM

1.1. PROBLEM STATEMENT

Western society provides an environment that is both technologically rich and intellectually challenging, creating the need for individuals who can make effective use of and contribute to the vast array of information available to us (Carnevale, Gainer & Meltzer, 1994; Papert, 1993; Schlechty, 1990). The skills required to be an effective citizen of the 21st century are based largely on information management in all subject areas. We have great opportunity to facilitate learning through the appropriate application of technology, including the use of 3-D learning environments.

Much of our educational system is not well suited to meet this challenge. In some respects, teaching styles and current day classrooms mirror those found in the prairie schools of the 1800s. In addition, distribution of resources, including computer technologies, remains sadly unbalanced. This does not fairly advance our children's opportunity to develop critical thinking, problem solving and information management skills to function well in today's environment.

According to Mecklenburger (1993), the characteristics of an "educated person" in society today are as follows:

> Because now we live in an information age and electronic networks are linking the world into a 'global village' (McLuhan, 1964), an educated person is one who has the ability to find what is known, then to think about what is known, to reflect upon changes in what is known, to explore, to share, to debate, to question, to compare and contrast, to solve problems, to engage in what today's educators call 'higher order thinking skills', and to contribute to what is known. (p. 42)

Parents, business owners and government representatives often mourn our children's inability to meet current day intellectual and professional challenges (National Alliance for Restructuring Education, 1994; Carnevale, Gainer & Meltzer, 1994; Schlechty, 1990). Curricular reform is often proposed as the solution, particularly in the areas of science, mathematics (American Association for the Advancement of Science, 1990; 1993), and creative and critical thinking (Sternberg, 1988; Weisberg, 1988).

According to data collected for Project 2061, a math, science, and technology literacy reform movement, American students' educational performance in the areas of science and math has decreased continuously since the late 1970s (American Association for the Advancement of Science, 1990; 1993). National (Carnegie Commission on Science, Technology and Government, 1991) and local (Council of Chief State School Officers, 1993) organizations express fear that our students are becoming less cognitively adept and less knowledgeable in a world that is becoming increasingly more complex. Students are not deriving *meaning* from their educational experience (Negroponte, 1995; Papert, 1993; Cunningham, 1992). Therefore, our educational system is attempting to respond to this issue through educational reforms, such as revising curriculum, establishing new learning standards, and incorporating the use of technology as an integral part of the learning process (NARE, 1996; BHEF, 1993; VRC, 1994; APA, 1992).

Our choice as educators, according to Schlechty (1990), should be to foster a love of learning in our students that will transfer from school to professional life. He says:

> The ability to think and solve problems, to take the creative turn, to draw upon a rich vocabulary based on a deep understanding of language and the human condition-- these are all attributes that thoughtful business leaders will seek in the future work force. (p. 4)

If we do not change the way we come at the educational process, we will indeed maintain and support the status quo. As stated by Schlechty (1990), "if you do what you've always done, you get what you always got."

There are those (Zemelman, Daniels & Hyde, 1993) who feel real change is occurring at the grass roots level through Constructivist curricular reforms. Through research and discussion, this movement has developed a set of characteristics of highly effective educational environments. Zemelman, Daniels & Hyde, (1993) state:

> While legislatures, blue-ribbon panels, and media sages have tinkered with the logistics of education, another quieter school reform movement has been growing. Our nations curriculum research centers, a dozen subject-matter professional associations, many capable individual researchers, and thousands of on-the-line classroom teachers have been struggling to determine what works in the different school subjects, and to clearly define best educational practice in each teaching field. These groups share a curriculum-driven view of education: they assume that if American schools are to be genuinely reformed, we must begin with a solid definition of the content of the curriculum and the classroom activities through which students may most effectively engage that content. Today, there is a strong consensus definition of best practice, of state-of-the-art teaching in every critical field. (p. 3-4)

These characteristics, summarized from a variety of sources (National Alliance for Restructuring Education, 1996; National Research Council, 1995; Vermont Restructuring Collaborative, 1994; Lewis, 1993; Bybee et al., 1989, 1991; American Association for the Advancement of Science, 1990, 1993; Harste, 1989; Hillocks, 1986; Anderson, et al., 1985) are listed in Table 1, below. They represent a fundamental shift towards student-centered learning, incorporating all of our human aspects and abilities: intellectual, emotional, social and creative.

Table 1 - Best Practices for Effective Education

LESS EFFECTIVE	MORE EFFECTIVE
Whole class teacher directed instruction	Experiential, inductive, hands-on learning
Student passivity	Active learning: doing, talking and collaborating
Prizing and rewarding of silence in the classroom	Emphasis on higher-order thinking using concepts and principles
Classroom time devoted to seatwork	Deep study of a smaller number of topics, utilizing inquiry and discovery techniques
Time spent reading textbooks and basal readers	Time devoted to reading whole, original, real books, and nonfiction materials
Thin coverage of broad subject matter	Responsibility transferred to students: goal-setting, monitoring and evaluation
Rote memorization of facts and details	Choice for students; topics, study partners, research projects
Stress on competition and grades	Enacting and modeling the principles of democracy
Tracking or leveling of students into ‘ability groups’	Attention to affective needs and cognitive styles of individual students
Use of special pull-out programs	Delivery of special help to students in regular classrooms
Use of and reliance on standardized tests	Descriptive evaluation of student growth, including qualitative/anecdotal information
‘Traditional’ administrator/teacher/student roles	Varied and cooperative roles for parents, teachers and administrators
Individual activities that foster isolation and competitiveness	Cooperative, collaborative activity; developing an interdependent community

This reform effort seeks to create an educational environment in which students take an active role in their learning process within a supportive learning community. This dissertation describes efforts to provide such an interactive, collaborative learning opportunity through the application of constructivist principles and 3-D interactive technologies in the classroom.

Constructivist educators strive to provide students with access to information “on demand”. Educational technologies can be utilized to facilitate such access to information including integration of computers, multimedia software and the Internet and World Wide Web into the curriculum. By accessing information in a variety of media formats and in an interactive fashion, students can make meaningful associations through their own explorations through these different technologies.

Development and integration of multimedia in the classroom have been positive steps towards truly interactive learning (Dede, 1992; 1994, Minstrell, 1992) . However, the student is often still primarily the passive recipient of information rather than an active meaning-maker. Creating support for knowledge construction within the student is a critical component to the success of developing self-motivated, intellectually stimulated learners (Wiske, 1994; Unger, 1994; Poplin, 1991; Duffy & Jonassen, 1992; Arnold, 1991).

This research was intended to provide the student with a system of accessing information and the means to create or re-create their own personal meaning from that information. It has been found that 3-D interactive environments can make a unique contribution to knowledge construction (Winn, 1995; Byrne, 1996; Merickel, 1992). By using the body in conjunction with visual and auditory perception, students are provided with a rich environment in which they can imbed and extend their understanding in an interactive fashion. In creating and experiencing a virtual world, students can attribute meaning to objects, relationships and behaviors in a way that mirrors their personal understanding, but that is not necessarily constrained by real world attributes that might limit the students’ perspective.

Virtual learning environments that are self-paced, immersive, and interactive have been found to be educative (Rose, 1996; Winn; 1993, 1994, 1995, 1997; Dede, Salzman

& Loftin, 1996; Byrne, 1993, 1996; Dede, 1994; Osberg, 1994b, 1997). It is the opportunity for self-directed study that is both engaging and meaningful.

1.2. PURPOSE OF STUDY

This research compares the application of constructivist principles through virtual environment development and implementation to traditional, non-constructivist practices in a middle school biology classroom. The purpose of this study was to better understand the value of constructivist practices on students' meaning-making and knowledge construction process.

Specifically, this research is designed to answer four questions: 1) Is *construction* of a virtual learning environment educationally efficacious? 2) Is *experiencing* a virtual environment educationally efficacious? 3) Does the construction process vary in educational value from the experiencing process? 4) How does world-building and experiencing compare to a traditional educational approach?

Previous research shows that students enjoy experiencing 3-D interactive environments (Rose, 1996) and enjoy creating them as well (Winn, 1995; Byrne, 1993, 1995; Bricken & Byrne, 1992; Osberg, 1993b, 1994b). But previous research in this field is undeniably slim. This study seeks to extend the knowledge base in this area by comparing the effect of two instructional interventions within a wetlands biology curriculum: constructivist practices, including virtual environment development and experience, and traditional pedagogy.

CHAPTER 2: CONCEPTUAL FRAMEWORKS

This study examined whether constructivist practices in the classroom help students make deeper, more meaningful knowledge constructions than those derived from traditional classroom practices. This chapter describes the relationship between the learning theory known as constructivism, the semiotic theory of signs, and the use of 3-D interactive environments as a constructivist learning tool.

The first section of this chapter describes the learning theory known as Constructivism. This theory describes the process of meaning-making, in which individuals construct mental models that ground their understanding in a deeply personal and unique fashion. Constructivists believe that certain activities and environmental enrichments can enhance the meaning-making process, such as active learning using kinesthetic, visual and auditory modalities, creating opportunities for dialogue, fostering creativity and providing a rich, safe and engaging learning environment (Brooks & Brooks, 1996.) A description of constructivist practices is provided, followed by a series of concrete classroom examples utilizing these practices.

Sign theory provides a means of alternative assessment of the meaning-making process by evaluating the richness of students' knowledge constructions. The semiotic model of sign, as defined by Peirce (1955) provides the conceptual model of meaning-making used in this study. The application of this model in education is then presented through the work of Cunningham (1992, 1997) and Shank (1997).

An introduction to 3-D interactive environments and their application as a constructivist learning tool is presented in the last section. Components of a particular virtual reality system are described, followed by a discussion on the perceptual aspects of virtual reality. Evidence supporting the use of virtual reality as a complementary learning tool to the constructivist learning paradigm completes the chapter.

2.1. CONSTRUCTIVISM

Constructivism is a learning theory describing the process of knowledge construction. Though constructivism is a learning theory, it is the application of what are often referred to as "constructivist practices" (Zemelman, Daniels & Hyde, 1993) in the classroom and elsewhere that provide support for the knowledge construction process.

Constructivism is not a spectator sport. By definition, knowledge construction is an active, rather than a passive process. The process of constructing one's knowledge can involve both cognitive (Cunningham, 1988, 1993) and physical constructions (Harel & Papert, 1991) of meaning, through the development of mental models or schemas (Johnson-Laird, 1980), as well as physical or virtual representations of knowledge (McClellan, 1996; Winn, Hoffman & Osberg, 1995; Winn, 1993, 1994; Papert, 1993; Duffy & Jonassen, 1992; Winn & Bricken, 1992; Mones-Hattal & Mandes, 1996).

Two valued tenets of constructivist practice are the process of collaborative learning and deep personal introspection into one's own learning process (Brooks & Brooks, 1993, 1996). Through dialogue, we form a network of understanding, a community of others with whom we can learn and share through discourse. Dialogue, however is not the only active means of knowledge construction at our disposal. Mental manipulation, visualization, and the process of developing, testing and discarding hypotheses (Shank, 1992, Shank et al, 1994) are also indicative actions of an individual actively engaged in the knowledge construction process.

This research is designed to test the value of actively constructing meaningful signs and relationships using virtual world building as one learning tool, and world experiencing as another. It has been found that creation and experience of virtual reality environments supports the students' active mental and physical engagement in the knowledge construction process. (Byrne, 1996; Rose, 1996; Winn, 1995; Osberg, 1993b). This study was designed to extend our knowledge about this relationship.

2.1.1. CONSTRUCTIVIST PRACTICES: AN OVERVIEW

The practical application of constructivist practices in the classroom presents additional challenges and benefits to both the teacher, and the student (Brooks & Brooks, 1993; Taylor, 1992; Patterson, Purkey & Parker, 1986). The challenge for the teacher is to provide relevant frameworks upon which the student can construct knowledge and understanding, and to act as a facilitator rather than knowledge-bearer during the process (Zemelman, Daniels & Hyde, 1993.) Students must become actively engaged in their learning experience, rather than act as passive recipients of information (Negroponte, 1995; Cunningham, 1992; Kraft & Sakofs, 1989.)

Some components of constructivist practices include:

1. Depth vs. breadth
One of the key issues that a constructivist teacher faces is the need to develop a sense of depth about a concept. This requires longer content modules, greater focus on process rather than product, and open-ended questioning techniques that require contemplation and assimilation of information (Brooks & Brooks, 1993).

2. Learning for transfer
The constructivist classroom is an environment based on inquiry, that leads to deep understanding of the concept under scrutiny. It is also an environment in which students will have enough time to develop mental models of the content, which will assist in moving that knowledge away from the primary content area, so that it can be applied elsewhere (Spiro et al, 1992a, 1992b).

3. Changing one's frame of reference through experimentation
In traditional classrooms, there is often only one 'right' answer. In the constructivist environment, naive beliefs are often the starting point for further discussion and discovery, and are not discounted as being 'wrong' (Lochhead, 1985, 1988; Minstrell, 1989, 1992; Minstrell, Stimpson & Hunt, 1992). Though formal scientific experimentation is not often introduced until at least middle school, the process of discovering cause and effect relationships is often employed even in the primary grades. (Strommen, 1992). This discovery process allows the child to reevaluate what they know, and to change their understanding based on what they have directly learned from their environment.

> 4. Implementation of cooperative rather than individual learning
> In many traditional classrooms, cooperative learning would be frowned upon, or might even be viewed as 'cheating'. Constructivism puts cooperation and mutual exploration at the top of the list. This frees students to bounce ideas off of one another, and fosters learning-in-dialogue rather than learning-in-isolation (Lewis, 1993; Brown & Palinscar, 1985).

The perceived benefits to a constructivist learning environment include holistic learning opportunities, the enhancement of collaborative/cooperative skills and time and appreciation for metacognitive reflection (Brooks & Brooks, 1993, 1996; Resnick & Klopfer, 1989).

Holistic learning encompasses absorption and synthesis of individual facts, building relationships between these facts and linking this knowledge with understanding of other knowledge domains. It is a process that involves engaging all of one's perceptual senses, creativity, and intellectual prowess in the learning process (Weisberg, 1988; Kraft & Sakofs, 1989). This study sought to provide an environment in which holistic learning could take place.

Expectations and outcomes are different in a constructivist learning environment than those found in the traditional classroom. Therefore, testing procedures must be redesigned to compensate for the expanded knowledge base that the student is developing. As a complement to the constructivist learning paradigm, alternative assessment is discussed in the next section.

2.1.1.1. Alternative Assessment

Part of the rhetoric surrounding the reform movement is specifically tied to the desire for accurate representation of what a student *knows* (Rose, 1995; Jonassen, 1992) and how that knowledge can be *transferred* to domains outside the school room. (Sweet & Zimmerman, 1992). The focus is on providing non-traditional means that allow students to show their understanding of a concept or process. It is also a much more complex, holistic approach to assessment.

Alternative assessment techniques, such as criterion-referenced, performance-based assessment, relate strongly to real-world experiences (Rose, 1995; Resnick, 1989). Performance assessments replicate the actions required to actually do the tasks, rather than referencing the tasks obliquely. However, it is not easy to develop or administer performance-based or other alternative assessment procedures (Herman, Aschbacher & Winters, 1992.) It requires more time, more willingness to engage on a personal level with students and more analysis. It also requires that the student be prepared to perform in a different manner than might have previously been expected (Perkins, 1993).

However, it is perceived that the benefits of performance-based assessment to the student can be extensive (Rief, 1990; Newman, Griffin & Cole, 1989; Bruner, 1971, 1990). There is often a heightened sense of personal accomplishment, more initial motivation to engage in the task and the perception of a stronger relationship between in-school and out-of-school activities (NARE, 1986; Herman, Aschbacher & Winters, 1992).

The process of developing performance-based assessment rubrics is similar in some ways to the design of traditional assessment. The designer must still tie the assessment to the instruction, determine the purpose of the assessment, select the tasks, develop criteria and ensure reliable scoring of the performance itself. The largest difference lies in the nature of the tasks that the student must undertake (Herman, Aschbacher & Winters, 1992), and the manner in which the data is interpreted. As stated by Winn (1993), ". . . instructional designers are wrong to assume that they can base instructional strategies on the analysis of an objective, standard world. Evaluation of learning can only tell us what students appear, or pretend to know, not what they really know."

Constructivist learning is an active process, and alternative assessment celebrates this active process (Herman, Aschbacher & Winters, 1992). Instead of testing for the "presence or absence of discrete bits of information" (p. 15), alternative assessment instead provides a means to understand whether "students organize, structure, and use information in context to solve complex problems" (p. 15). This relates to the manner in which the semiotic model of sign can be used as an alternative assessment tool. By analyzing the relationships between signs and symbols, instead of evaluating the discrete signs themselves, a holistic picture of the students' understanding emerges. The process by which these relationships come into being is an emergent phenomenon (Shank, 1992), which is iterative, personal and ongoing.

Simmons too (1994) states the case for iterative, ongoing, and imbedded assessment, which can be both self and instructor-administered. She states:

> Assessment is not something that we tack onto learning: it is an essential *ongoing* component of instruction that guides the process of learning. Ongoing assessment uses exhibitions, student explanations of concepts, the writing of a poem or a song, or any number of other thought-demanding performances to evaluate and reflect on students work (p. 22).

Assessment can be used to build understanding through reflection and iteration. There is great promise for deeper understanding and appreciation of the creative, generative process we call learning when a student is aware of scholastic expectations and understands how to effectively review and critique his or her own work. Simmons (1994) outlines this process in three steps:

1. The teacher must help students understand from the outset the standards by which their work will be judged.

2. Students must document their work process for the duration of the project or unit.

3. Through performance and feedback, students come to understand the complex nature of judging and improving upon one's work.

This last point is especially crucial, as "taking the time and energy to reflect on and improve one's work is essential to the understanding process itself" (p. 124). Instead of the traditional black-and-white, single score assessments usually meted out by traditional instructors, students learn instead that there are indeed many shades of gray, that it is difficult to judge and to be judged.

Rief (1990) also supports self-assessment, especially in middle-school aged children. In her utilization of self-assessment techniques of student writing over the course of a year, Rief came to understand that it was the students' personal dialogue that was most valuable. In establishing criterion for portfolio work, she found that it was best if she imposed *external* criteria by which the portfolio would be judged, and allowed the students themselves determine the *internal* criteria:

> I discovered that the students knew themselves as learners better than anyone else. They set goals for themselves and judged how well they had reached those goals. They thoughtfully and honestly evaluated their own learning with far more detail and introspection than I thought possible. Ultimately, they showed me who they were as readers, writers, thinkers, and human beings (p. 25-26.)

In essence, what Rief (1990) discovered was the intrinsic motivation so necessary for developing deep understanding and personal meaning. As one of her students states: "Now I know that in order to write something well, you have to care about it. The first important thing is that you like a piece of writing, then you worry if anyone else likes it" (p. 29). At the core of the learning process is to acknowledge the intrinsic value of learning to ourselves. At the end of the year, in describing the above students' work, Rief (1990) states "she has a message for her reader, because the message is always for *her*, first" (p. 31).

In practice, both traditional and alternative assessment of students' performance should require an understanding of how a particular student came into the learning process, including their cultural background, personal learning style and what they accomplished in relative terms while engaged in the learning process. It becomes a very delicate, finely tuned relationship between assessor and assessed. This balance is easier to maintain when working with alternative practices (Simmons, 1994).

2.1.2. CLASSROOM EXAMPLES OF CONSTRUCTIVIST PRACTICES

Poplin (1991) attests that meaning can be constructed two ways: through new experiences, or through contemplation and recalled experiences. She feels that the latter technique is given short shrift in our current educational system, and yet it is through this reflective process that we come to know concepts deeply.

Poplin (1991) states that the reasons children do not learn are four-fold:

- Insufficient involvement in learning
- Insufficient previous experience
- Insufficient interest
- Mismatched previous experiences

To be ‘sufficiently involved in the learning process’, Poplin (1991) states:

> Learners cannot passively construct new meanings; they can passively respond to lectures, worksheets and even passively apply their short-term memories. For example, many students memorize lists of vocabulary words until the test is over, yet never integrate the new vocabulary into their own language (p. 3).

Regarding a child’s ability to make meaningful linkages to new information, the fourth point that Poplin (1991) makes with regard to why children do not learn is that some individuals have mismatched previous experiences, most notably those that are cultural or gender-based. She states:

> The most prevalent mismatch in schools is the failure of most of the curriculum to take into account perspectives of cultures other than standard middle-class Anglo-Saxon ones. The evidence of our ethnocentricity is appalling, and can be found in most teacher’s guides. The guides offer only one answer to comprehension questions. The constructivists point out that the meaning of a text (or other information source) is constructed by the reader (or creator), not simply by the author or the curriculum guide author. This meaning, being personal in nature, is thus subject to the reader’s experiences. (p. 4)

Arnold (1991), states that “the curriculum here is neither for a body of knowledge developed by dead white men which everyone should know, or for ‘political correctness'" (p. 6). She espouses a curriculum-based reform effort, supporting knowledge construction:

> The attempt to separate content and process, or to make one subservient to the other, belies a faulty epistemology. James (1974) tells us that knowledge involves both *question* (process) and *answer* (product or content). One of the major faults of schooling, and perhaps a reason why content tends to be denigrated, is that we are constantly giving students answers to questions that they have not asked. (p. 8)

Regarding the value of content Arnold (1991) states that "an educated person knows *how* to learn, but also knows about significant issues and ideas". To develop a curriculum rich in meaning, she suggests that such a curriculum embodies three distinct yet interrelated principles:

1. Material should be genuinely important and worth knowing.
2. Meaningful curriculum deals directly with values and beliefs about the content area.
3. Both content and methodology must relate directly to the needs and interests of the student population, i.e. developmental appropriateness.

These thoughts are also addressed in "A Practical Guide to Alternative Assessment" in that there are also the metacognitive and affective components to learning. According to Herman, Aschbacher & Winters, (1992), "meaningful learning is intrinsically motivating" (p. 16). By focusing on developing a "thinking curriculum" (Resnick & Klopfer, 1989), both process and product are reinforced. In a thinking curriculum, the focus is on in-depth, thematic learning that relates to real-world issues, and espouses the utilization of holistic, alternative assessment procedures, providing a direct connection of content and process to the learner's background. In this manner, the essence (Brooks & Brooks, 1996) of the content can be fully addressed in a manner that is directly accessible to the student.

In the next section, three classroom examples of constructivist principles in practice are described. Harvard's Project Zero has led the way for many constructivist practitioners by providing a framework for structuring a constructivist curriculum. Simultaneous to and separate from the Harvard project, Apple Computer developed the Apple Classroom of Tomorrow program, focusing more fully on the use of technology as a learning tool in the classroom. The KCOT classroom at Kellogg Middle School, a constructivist environment that incorporates principles espoused by both ACOT and the National Alliance for Restructuring Education is presented last.

2.1.2.1. Project Zero: Harvard's Teaching for Understanding Framework

At the Harvard Graduate School of Education, four principles have been developed that support the Teaching for Understanding framework, as part of Harvard's *Project Zero* (Unger, 1994). These principles are:

1. Learning should be generative, and go beyond the subject matter covered. Students should be encouraged to apply their learning "outside the box".
2. Clear educational goals should be established and shared with students, thereby empowering them to work towards high, known, and understood standards.
3. Assessment should be performance-based, giving the students the opportunity to demonstrate their knowledge in a manner meaningful to them and accessible to others.
4. Assessment should be ongoing and iterative.

Wiske (1994) describes how teaching for deep understanding changes the rules in the classroom, especially how the intellectual property of the classroom can be best utilized. She says:

> Understanding is not a private possession to be protected from theft, but rather a capacity to be developed through the free exchange of ideas. (p. 19)

Using the Teaching for Understanding framework, Wiske makes note of the shifting roles and responsibilities in a classroom dedicated to emphasizing understanding. First and foremost, the lines between *teacher* and *learner* become blurred, and at times the roles are reversed. This provides an opportunity for students to demonstrate their skills to a wider audience, and the teacher to acknowledge individuals' scholastic capabilities in a different light than might normally occur. This was facilitated at Kellogg Middle School by providing the students an opportunity to create learning environments that would be experienced by other students; to become the "teachers" for that environment.

Second, the teacher must be willing to share what Wiske refers to as "intellectual authority" (p. 20). Instead of the objective knowledge base and commensurate power residing strictly with the teacher, intellectual authority is shared under this framework, leading to respect, consideration, and empowerment for both teachers and students. In Wiske's (1994) words:

> Certainly, teachers must not abandon their authority, which derives legitimately from the knowledge of subject matter and their responsibility for guiding students. But they must encourage students to develop their own ways of exercising authority. In short, teachers must be in authority, without being authoritarian (p. 21).

Wiske uses the metaphor of the key of knowledge being granted to every student by simply "leaving the door (to knowledge) unlocked" (p. 22). In this fashion, we can create an open atmosphere for learning that provides for guidance and assistance, yet celebrates students' intrinsic value and autonomy (Brooks & Brooks, 1996).

2.1.2.2. The ACOT Program

The ACOT (Apple Classroom of Tomorrow) format of classroom instruction is based on constructivist pedagogy, supported through educational technology. ACOT is a program supported by both Apple Computer, Inc. and the National Alliance for Restructuring Education. The mission of the ACOT program is to "change the way people think about and use technology for learning" (Yocam, Filmore and Dwyer, 1992; Dwyer, 1994).

Since its' inception in 1986, the ACOT program has been working directly with teachers and schools to provide teacher training and technology in the areas of:

- Constructivism
- Authentic assessment
- Integration of technology into the daily curriculum

Though the program has sometimes been criticized for conducting most of its own evaluation, some independent research has been conducted that indicates that this and other technology-rich programs have a positive effect on students learning (Kulik & Kulik, 1991; Baker, Herman & Gearhart, 1989).

The ACOT Professional Development Center contrasts traditional instruction and constructivist learning in the following fashion (Apple Computer Inc., 1994):

> *Instruction*-- lecture, drill and practice-- is a great way to introduce skills or concepts, or build awareness, or reinforce some set of actions that can be replayed habitually. When breadth is valued over depth in curriculum, instruction is one way to make sure you cover the necessary content in a given amount of time.
>
> When depth and understanding are the desired outcomes, however, *knowledge construction* is a better strategy to help learners personalize and deeply internalize ideas to create situations where skills and concepts can be applied in different contexts to solve problems; to explore or generate ideas; and to generalize and synthesize knowledge. (p. 3-4)

Table 2, below, presents a summary of Apple's perception of the differences between instruction and knowledge construction practices in the classroom.

Table 2 - Comparison of Apple's Instruction and Knowledge Construction Practices

FUNCTION	INSTRUCTION	CONSTRUCTION
Classroom Activity	Teacher-centered; didactic	Learner-centered; interactive
Teacher Role	Fact teller; expert	Collaborator; learner
Student Role	Listener; always the learner	Collaborator; sometimes the expert
Instructional Emphasis	Facts; memorization	Relationships; inquiry and invention
Concept of Knowledge	Accumulation of facts	Transformation of facts
Demonstration of Success	Quantity	Quality of understanding
Assessment	Norm-referenced; multiple-choice items	Criterion-referenced; portfolios and performances
Technology Use	Drill and practice	Communication, collaboration, information access and retrieval, expression

By providing opportunities for relevant, timely, self-directed study utilizing technology-based instruction, collaborative learning and alternative assessment techniques, the differences in classroom practices and attendance is substantial. Dwyer (1994), in discussing ACOT's approach to the development of critical thinking skills states:

> In-depth study of a sample of students' thinking processes began to show significant change in the way they thought and worked. . . . A four-year longitudinal study showed the greatest difference to be the manner in which they organized for and accomplished their work. Routinely, they employed inquiry, collaborative, technological, and problem-solving skills uncommon to graduates of traditional programs (p. 6-8).

The positive effects of the program have been far-reaching. As stated by Dwyer (1994), "we watched technology profoundly disturb the inertia of traditional classrooms" (p. 9). Benefits have been found with regard to both student and teacher behaviors. Regarding students, one benefit is the fundamental change seen in the way that children think about their personal learning processes, organize materials and engage in the learning process itself. This is directly analogous to Cunningham's (1992) description of reflexivity, discussed in the section on educational semiotics. According to Dwyer and his colleagues, these skills are a direct outgrowth of the integration constructivist learning principles coupled with the daily use of computer technology into the classroom. From their research, ACOT project coordinators have seen a marked increase in the development and application of students' critical thinking skills both in and outside the classroom.

With regard to teachers, ACOT-conducted research (Dwyer, 1994) has found that "teachers reported and were observed to interact differently with students-- more as guides or mentors and less like lecturers. . . For many teachers, personal efforts to make technology an integral part of their classrooms opened them to the possibilities of redefining how they went about providing opportunities for students to learn" (p. 6).

The other challenge is how to account for the demonstrated proficiencies such as creative problem-solving, collaborative learning and alternative forms of communicating about one's knowledge. Traditional assessment systems do not allow for much deviation from quantitative, clearly defined measures, including those measurement rubrics employed at the state and national levels. As stated by Dwyer (1994) "Teachers struggle with the new methods of evaluation that could capture the novel ways that students were demonstrating their mastery of skills and concepts" (p. 6-7). The merits of alternative assessment have been previously addressed in section 2.2.1.1.

Even with the success that ACOT has been able to demonstrate, there are still barriers and challenges that make the transition between a traditional and constructivst classroom environment difficult. However, pilot programs exist in many school environments. This project took place in one such environment, Shoreline School District's KCOT program. A description of this program is provided in the next section.

2.1.2.3. The Kellogg Classroom of Tomorrow (KCOT) Program

The environment in which this study was conducted is called KCOT, the Kellogg Classroom of Tomorrow. It is located in the Shoreline School District in Seattle, WA. Simultaneous with the development of the ACOT program, the Shoreline School District engaged in district-wide school reform planning, focusing on many of the same practices as described in the ACOT program.

In a document entitled *Shoreline Learning Priorities* (Simpson, 1995), Dr. Marilyn Simpson helped Ms. Marcia Morrison, district Director of Student Learning, define and refine the process by which these learning priorities could be accomplished within the district as a whole. The four priorities are directed at the teacher, in the interest of best assisting students to become responsible life-long learners (Senge, 1990) who can incorporate the skills gained in the classroom in all environments. Though not all of the subcomponents could be considered exclusively ‘constructivist’, as a whole they do present a very constructivist approach.

The four priorities are:

- Teach for Intellectual Development
    1. Critical and creative thinking skills development
    2. Demonstrated competencies in core curriculum
    3. Effective use of technology in the classroom in support of learning
    4. Application of learning skills to relevant, real-life situations
- Make Learning Meaningful
    1. Appreciation of diversity of learning styles and personalities
    2. Appreciation and application of appropriate teaching styles
    3. Giving students the opportunity to own their learning experiences
    4. Developing a passion for life-long learning
- Use Authentic Assessment
    1. Set high standards for self and students
    2. Developing a dynamic approach to a changing world
    3. Demonstrate competencies through performance
    4. Encourage active participation in our democratic society
- Focus on Students Becoming Producers and Contributors
    1. Contribute to others in class in and community

2. Foster value as an individual and as a contributing member of society
3. Use learning skills in real-life situations and for real rewards
4. Interact/team with other teachers and community members.

The KCOT program was developed to address these issues even more fully, and to provide a technology rich-environment in which students could work. By adopting and refining the standards established by Apple and the National Alliance, Kellogg Middle School has fostered the development and support of a constructivist classroom environment within the confines of the "traditional" middle school.

KCOT is one of 6 self-selected program options available to Kellogg 7th and 8th graders. In contrast to the traditional discrete-subject program, KCOT places emphasis on long-term, thematic, project-based learning. The program description, listed in the Kellogg Middle School (1996) Program Options brochure reads as follows:

> The KCOT program provides a technology-rich student-centered learning environment of high standards and ambitious objectives. The program is a two-year curriculum that combines the core concepts of the 7th and 8th grade areas in English, math, social studies and science. Students learn through projects as well as specific skills classes. Program-set standards based on state requirements replace traditional grades. Technology, community resources and family play vital roles in student support.
>
> Students in KCOT take responsibility for their learning by helping determine standards, developing projects, securing resources, and taking ownership of their community. They work both individually and in groups, utilizing a variety of learning strategies and techniques. Students use technology as a regular part of their day. Self-direction is essential to success (p. 2).

Other program documents highlight the cooperative, collaborative nature of the KCOT classroom, and the integration of performance-based assessment techniques. KCOT students meet for a single four-period (out of six periods total) block daily, during which they pursue core requirements as described above, but also take part in community-based projects. Many of the students participate in science, technology, and math fairs held at the district, state, and national levels.

Another aspect of the KCOT program is its' staff. The teachers who participate in the KCOT program are progressive, willing to take risks in the interest of better education and technologically savvy. They are often asked by other teachers in the district for assistance in setting up similar environments elsewhere. For example, Mr. Mike McMann, originally a KCOT teacher, has taken on the role of district-wide Teacher Development Coordinator. In his expanded role, he has the opportunity to teach other teachers about how the constructivist classroom functions, how to integrate technology into the curriculum and how to develop alternative assessment programs that best fit the needs of both teachers and students, by utilizing the example set in the KCOT environment.

At its inception in 1993, the program had two teachers, two classrooms and 53 students. In 1994, the program expanded to incorporate 4 teachers, 4 classrooms, and 120 students, plus the invaluable services of Mr. McMann.

Much of the knowledge gleaned from the KCOT classroom is made available to other teachers in the district through workshops and seminars on constructivism, active use of technology as an integral part of the curriculum and authentic or performance-based assessment. Most of the classroom practices and reference information dispersed in these seminars has been tried and tested in the KCOT classroom prior to distribution. As testimony to support the efficacy of the KCOT classrooms, the district level coordinator now provides training and support to teachers from all over Washington State, and at the national level as well.

The KCOT program is a good example of the kind of classroom described by Schlechty (1990) in his article on what real reform can offer. He suggests:

> Rather than being concerned with scope and sequence, teachers would concentrate on richness and texture. The assumption of course, is that the richer the curriculum (I did not say the more *diverse*) the richer the knowledge-work products will be. If the texture of the curriculum is such that students can grasp and handle it (intellectually speaking) as opposed to some of the pallid materials that now confront them, surely more students will be attracted to the field of knowledge work.

> As workers, students are active participants in the knowledge-work process. Their job is to take the knowledge embedded in the curriculum and process it in such a way that *makes it their own*. (p. 6).

The KCOT program is not limited to the "best and brightest" students. In fact, one document states "learners with different abilities and interests will be challenged to do their best work individually and in small groups." My experience with the KCOT program was indicative of a broad-based effort to integrate, interest, and support students from a variety of cultural backgrounds, learning styles and intellectual abilities.

KCOT was an optimal environment in which to conduct this study. The classroom used to conduct the world building exercise had 14 computers around the perimeter. Students were used to constructivist learning practices, including participation in project-based, cooperative learning. No time was wasted "converting" students to a new way of thinking or acting. It was an energized environment, filled with individuals interested in taking charge of their own learning process, unafraid of technology, curious, socially aware, and willing to take risks in terms of their personal involvement in this high-stakes, high-visibility project. In short, it was an exceptionally exciting place to have had the opportunity to conduct such a study.

2.1.3. CONSTRUCTIVISM AND SEMIOTICS

If the process of constructing knowledge relies heavily on the use of symbols and signs, we need a model of how signs and symbols are created, and how they come to have meaning. Based on the seminal work of Peirce (1955), the traidic model of sign describes the components of signs, and how signs relate to one another. This model serves a dual purpose: it describes the relationship of signs to their internal components, and it describes the relationship of signs to other signs. In the next section, this model will be described, including its application within education.

2.2. SEMIOTICS

Semiotics, as described by Saussure (1916), is the “science that studies the life of signs within society”. Since the days of Plato and Aristotle, the study of man’s relationship between mental representations and the ”real world” have been the source of extensive inquiry by philosophers (Kant, 1990; Peirce, 1977), linguists (Saussure, 1916; Eco, 1979, 1984), psychologists (Piaget, 1954,1977; Morris, 1964), and, as of late, educators (Cunningham, 1992, 1997; Shank, 1992, 1997; Driscoll, 1989, 1997).

Saussure’s statement provides a perspective that signs have a life, and that life is constructed within the confines of a society. The relationship between signs, what signs represent (objects), and the mental process making that connection are described by Cunningham (1992) in Figure 1, below. Much of Cunningham’s work is based on the models developed by Peirce (1955), including this triadic representation of the sign process.

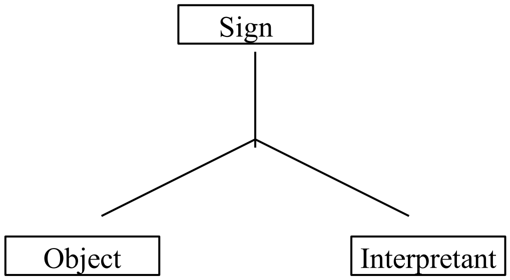


Figure 1 - Traidic model of the sign process

Signs, objects and interpretants represent the structural components of meaningful knowledge constructions. Cunningham (1992) says a sign “stands for something called the object, by linking it to an interpretant, and an additional sign that stands for some aspect of the object. A sign thus mediates between the object and its interpretant.” (p. 172)

Signs are used to construct representations and relationships between representations. They have value because they allow us to compact information into a format that can be referenced within different contexts, leading to different understandings. Language is one such example; the same symbols, reconfigured in different sequences lead to entirely different understandings. Even icons, when presented in a context-free environment can mean different things to different people. The very malleability of signs is what gives them so much power, yet it is the signs that have been granted common meaning that provide us with the means to communicate with one another.

In the model above, the interpretant is the “outcome or the effect of the sign”, which indicates that different signs may reference different aspects of an object, leading to different outcomes or effects. The process of creating the outcome or interpretant is a type of reasoning called *abduction*, according to Peirce (1955). This term has been subsequently adopted by other semioticians (Cunningham, 1992; Shank et al., 1994). Abduction is a type of reasoning that combines both deductive and inductive characteristics. As such, abduction is a form of inquiry that attempts to uncover the essence of an idea or object by both top-down and bottom-up analysis.

To illustrate the differences between deductive, inductive and abductive reasoning, Peirce (in Cunningham, 1992) used the following example:

The Deductive Syllogism:

Sign: All the beans in this bag are white.
Object: This bean is from this bag.
Deduction: This bean must be white.

The Inductive Syllogism

Sign: This bean is from the bag.
Object: This bean is white.
Induction: All the beans in this bag are probably white.

The Abductive Syllogism

Sign: This bean is white.
Object: All the beans in this bag are white.
Abduction: This bean is possibly from this bag.

In the abductive syllogism above, the white bean is the sign, the beans in the bag the object and the last statement the interpretant or outcome, as referenced by the relationship between the sign and object. Shank et al.(1994) states that “abduction operates through experiences as given in order to establish some meaningful hypotheses about the states of affairs behind the observations” (p. 35).

This process of experimentation is an important component to making meaningful knowledge constructions, according to Shank (1992). Children (and adults for that matter) often learn by trial-and-error. The abductive model, if taught, allows individuals to metacognitively assess their approach to a particular problem. Instead of random trial-and-error efforts, concious hypotheses can be formulated and tested. This allows individuals to make stronger connections between their assumptions, and their discoveries.

In the next section, Cunningham’s (1992) model of an educational semiotic is described. The pilot project at Kellogg Middle School presented an opportunity to utilize Cunningham’s model by providing the framework for student discussions about visual and interactive metaphors.

2.2.2. AN EDUCATIONAL SEMIOTIC

Cunningham has long been a proponent of sign theory, and of constructivism. Much of his current writing (1988, 1992, 1993, 1997) describes how an 'educational semiotic' could be utilized within the classroom context. In Cunningham's model, he details the cognitive process in terms of four components: *sign, semiosis, inference,* and *reflexivity*.

Signs

Signs, as mentioned above are metaphorical or analogical referents to some aspect, concept, object, or relationship. Cunningham describes a triadic relationship (as illustrated in section 2.1.) that provides unlimited referential capability to the individual. As mentioned above, the triad consists of the sign itself, the object that the sign represents and a mediating factor called the interpretant (Peirce, 1955). Cunningham says that the interpretant represents "the 'effect' or outcome of the sign process" (p. 172.) *Effects* can be broadly classified into thoughts, actions and feelings (Houser, 1987). Cunningham adds that interpretants are also signs and so can stand for anything as well, providing the basis for iterative, referential interpretation.

Cunningham says that signs are context-sensitive. The roles of the same sign/object/interpretant relationship "emerge from the context in which they occur, not from some *a priori*, context-free structure" (p. 173). To continue the thought, "Reality is what our sign structures reveal, which is our current understanding" (p. 174).

Houser (1987) states that signs can represent objects in one of three ways: "as icon, index or symbol" (p. 175). Icons represent objects by "resembling or imitating the object" (p. 175), similar in a way to Bruner's (1966) notion of iconic forms of representation. An index refers to its object by virtue of an actual link between the sign and the object. "Such signs serve as evidence of the object and in a real sense demand that we pay attention to them. They are entirely contextual and immediate" (p. 175). An example is the old adage "where there's smoke, there's fire." In this case, the smoke indexes the presence of fire.

In comparison, Houser (1987) states “symbols refer to their objects by virtue of a law, rule, or convention” (p. 175). Language is one such example. Symbols require syntax, because “it allows a code system to combine and recombine signs in a potentially indefinite number of ways” (p. 176). Code systems are important, because they are used to “structure our experience” (p. 176).

Semiosis

Semiosis is the process of making meaning as mediated by signs, and the interpretation of those signs. Peirce (1955) calls this process the “cognition produced in the mind” (in Nöth, 1995, p. 42). Cunningham (1992) says that the metaphor, a type of sign, is a designation by implicit comparison or analogy, as do Lakoff & Johnson (1980).

Lakoff & Johnson, (1980) however, go one step further. They provide evidence that metaphor is not only descriptive, it is also constraining. An example is the analogy “time is money.” In this example, one can get a sense of the value-laden nature of some metaphors. In western society, time is valuable, and so is money. Therefore, the two can be equated in a meaningful fashion within the context of the society that created the metaphor.

The negative impact of these constraining influences can be quite deep, especially when applied in an educational setting. Expectations can be formed and solidified that are based on metaphor, not on fact. Examples of this can be seen with metaphors associated with gender (Harding, 1991), race (Kohl, 1994), and equitable or moral classroom practices (Clark, 1990).

A classic educational example provided by Cunningham (1992) is the analogy “mind as container” in contrast to “mind as a laboratory.” In the first analogy, the student is present in the classroom to be filled with the knowledge provided by his instructors and his materials. In the second, the possibilities for experimenting with thought and learning are provoking indeed (Shank, 1992; Shank et al., 1994). Instead of viewing the students as repositories for extant knowledge, we can instead expand the knowledge base by experimenting with different content mixtures and educational processes. This attitude is often found in what Cunningham describes as a semiotics-based classroom. It changes the role of education and of the teacher completely. In the first instance, the teacher is the source and the student the receptacle; in the second, the teacher is a guide and the student a scientist. In Cunningham's words:

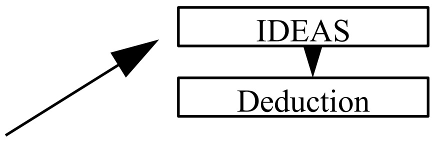
> The focus now is not on what is constructed but on the construction process itself; not knowledge, but the processes whereby something can become known; not what we know, but how we know it. Our job as educators is to provide models of the knowledge construction process and then nurture students' attempts to model. (p. 179)

Cunningham (1992) also expands Gardner's (1983) view of multiple intelligences to encompass not just ways of knowing, but also of representing knowledge in the mind of the individual. He says that there are no superior forms of representation-- that we "must avoid the dogmatism of 'right' and 'wrong' thinking within any particular intelligence" (p. 180). This opens the door to a new way of thinking, teaching and learning. Cunningham continues:

> We have to shift to pedagogical strategies that promote a student's ability to see that multiple perspectives may be brought to bear on a problem; that coming to understand another's view requires dialogue, not simply listening; that learning can and often should occur in a social setting, not as some private act; and that learning should be situated within realistic contexts about which the students care or about which they have made some kind of commitment" (p. 181).

Inference

Both Cunningham (1992) and Shank et al. (1994) describe the nature of the process of thought in terms of inference. In Cunningham's (1992) view, if signs are complete equivalencies for the objects they represent, and (as some semioticians contend) all thought is in signs, then thinking is fundamentally inferential. We infer "an object from its sign, and that inference, the effect of the sign, is the interpretant" (p. 184-85). This process is described in Figure 2, below.



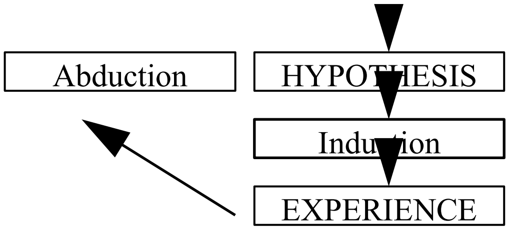


Figure 2 - Types of Inference

Recall that Shank et al.(1994) state that abduction operates “through experiences as given in order to establish some meaningful hypotheses about the states of affairs behind the observations” (p. 35). In this manner, individuals develop new ideas (general statements) about which they can develop specific hypotheses which can then be tested through experience. The results of this process contribute to the knowledge base, through abduction, of that individual. Cunningham (1992) states:

> Regarding semiosis as systems of beliefs and abduction as the primary mode of building new beliefs, places inquiry, in some form or another, squarely back where it belongs, within the capability of every person. (p. 186)

Reflexivity

Reflexivity, in Cunningham’s view, is “awareness of the processes of semiosis” (p 187), a form of metacognition. In his words “A reflexive analysis of the metaphors by which we live will allow us to reconsider them” (p. 188). He describes one way in which it could affect the way we teach:

> One consequence of an emphasis on reflexivity in our courses would be to coalesce the various subject matters, revealing the unity underlying them and rendering their separate treatment ill advised. . . An important component of reflexivity is the development of a informed skepticism, a healthy distrust of things at their face value and an openness to explore new interpretations, new sets of beliefs (p. 188-189).

Though Cunningham’s model is robust, it is still incomplete even by his standards. As he states, we will always have an obstructed view of reality, because “signs are jointly determined by the constraints imposed by reality and by the semiosic structures of the cognizing organism" (p. 190). Regarding the semiosic process itself, he says:

> It is a difficult and subtle discrimination to decide when to intervene and when to let students struggle with the construction process. . . In my experience, some students are unable or unwilling to assume responsibility for their own learning. Those who are unable should be coached. Those who are unwilling need to be persuaded (p. 190-91).

Shank (1992), too, has tried to build classroom practice around a semiotic curriculum. In his view what is needed is teacher re-education, based on a curriculum that emphasizes semiotics as the basis for their own learning. Only through practical, visceral experience will the value of this educational semiotics paradigm become obvious.

2.2.3. SIGN THEORY AS AN ASSESSMENT TOOL

Sign theory can be used as an assessment tool to evaluate the meaning inherent in a representation. However, a balance must be maintained between the value of interpretation (art) and the value of consensual understanding. For example, to understand the value of a virtual learning environment, one must ask both creators and experiencers what they derived from their design or experiential encounter with the environment. It is not just a question of whether students remember discrete aspects of the environment. It is more a question of what they derived from it in a holistic fashion.

Cunningham's (1992) model formed the meaning-making groundwork for my research study, as can be seen from the examples cited above. The intention in this study was to create an environment in which his educational semiotic could be employed, especially in overt consideration of the students' and teachers' deeply held beliefs and values about signs and their referents; an inherent component in virtual world design.

In the next section of this chapter, relevant aspects of virtual reality and its use as an educational learning tool will be explored.

2.3. 3-D INTERACTIVE ENVIRONMENTS (VIRTUAL REALITY)

Computers are symbol-system manipulation tools (Kay, 1990; Duffy & Jonassen, 1992; Winn, 1995). Advances in computer technology has allowed for the development of real-time, 3-D graphic, auditory and kinesthetic environments in which the student can be perceptually “immersed”. Optimal learning environments should be, according to Scardamalia, et al (1989) “active, learner-centered, engaging, relevant and robust.” Therefore, the characteristics of 3-D interactive environments are closely aligned with those of an optimal learning environment.

In this section, the case is made that 3-D interactive environments are a tool through which educators can provide an educational environement grounded in the principles semiotics and constructivism.

2.3.1. INTRODUCTION

We live in a technological, information-rich environment (Negroponte, 1995; Papert, 1993; Forman & Pufall, 1988). The Internet, for example, was originally developed as a direct communication link between government and scientific laboratories. With the increasingly widespread use of global communications such as the Internet and World Wide Web (WWW), we have expanded access to vast information, fostering the need to make sense of and assimilate this information in a meaningful way. This example of information access is just one aspect of our society’s focus on technology and science; areas of expertise that can be quite complex. The need for knowledgeable individuals in these areas is great (Project 2061, 1993a, 1993b; Lewis, 1995). Therefore, the need for a better means of teaching complex subjects is also a high priority. (NARE, 1996).

To accomplish this, we must be able to move beyond our old understanding of education (Apple Computer, Inc. ACOT Program, 1994; Arnold, 1991; Poplin, 1991), and to focus instead on developing a sense of *meaning* from the information with which we work, and the manner in which we make use of it (Fosnot, 1992, 1993; Cunningham, 1992; Bruner, 1990; Deely, 1986).

Information can be provided in a variety of ways, including through technologies such as virtual reality. In this study, students had the opportunity to both create and experience a virtual environment; both examples of experiential learning. The use of virtual reality ties to the precepts set forth in constructivist pedagogy in both a cognitive (mind), a somatic (body) form. In the virtual world, the knowledge construction process is made concrete by providing the student the ability to create and experience their own representations, or to manipulate the representations of others in a meaningful fashion. Though this capability is not always limited to virtual reality, the level of personal and shared interaction achievable with this technology makes it a compelling means for displaying and interacting with information. This ability is especially valuable when students interact, physically and directly, with objects and processes that are not accessible to the senses in the real world. From this standpoint, we can explore how the application of constructivist and semiotic theory through the creation and experience of virtual environments may provide one means of meaning-making for the student.

2.3.2. VIRTUAL REALITY DEFINED

Virtual reality has many meanings. In this study, the 3-D interactive environments that are referred to as "virtual reality" are described as follows: a computer generated, three dimensional environment in which the student is an active participant. (Bricken, 1991; Bricken & Byrne, 1992). The perceived advantages of the virtual environment as an instructional tool include whole body experiential learning (Osberg, 1993a), presence (Hoffman, Prothero, Wells, & Groen, 1996; Hoffman, Hullfish & Houston, 1995; Barfield & Weghorst, 1993), multiperceptual engagement (Brill, 1993), the opportunity to change perspective at will (Dede, Salzman & Loftin, 1996; Loftin & Kenney, 1995; Loftin, Engelberg & Benedetti, 1993), and abstract concept representation (Byrne; 1996; Winn, 1993, 1994; Winn & Bricken, 1992). Soon, multiparticipant, collaborative environments will also be available (Osberg, 1994b).

Virtual reality systems include the main processor, an input device of some kind (such as a 3-D mouse, glove, joystick or keyboard) and a visual display system. Visual displays can include:

- Single image on a flat screen.
- Stererscopic image on a flat screen, requiring the user to wear 3-D shutter glasses to the resolve dual images, providing the sensation of depth.
- Headset, helmet or goggles in which two different images are displayed on separate screens. The images are then combined in the visual system, resulting in the perception of depth and movement through the virtual space.

In addition to the components above, a tracking system is incorporated to describe where the participant is within the virtual environment. Trackers are found on the input device, and often on the helmet as well. They provide real-time relative coordinate information to the processor. By tracking the participant's movement in physical space, that movement can then be translated to the virtual environment so that the participants' point of view is changed to reflect that movement.

Virtual reality is similar to multimedia in that it is multiperceptual. Visual, auditory and haptic senses are engaged to navigate and interact within the environment. It differs from multimedia, however, in three distinct ways:

1. The whole body can be used to navigate and interact within the virtual space.

2. The technology can engender a sense of *presence*, the perceptual quality of being in the virtual environment, rather than in physical space.

3. The participant has substantial control over movement and interaction within the environment, rather than navigation by pre-programmed controls.

In this study, an immersive virtual reality system was used, including the main processor, a 6-D mouse which tracked hand movements in X, Y, Z, and roll, pitch, and yaw. The headset had two speakers and two LCD panels mounted in a fully enclosed helmet.

2.3.3. PERCEPTUAL ASPECTS OF VIRTUAL REALITY

Virtual reality is often promoted on three grounds; its multisensory capability, 3-D representation and animation, and the sense of perceptual "presence" that comes from combining the first two factors (Hoffman, Prothero, Wells & Groen, 1996). The primary sense utilized in virtual environments is visual, though certainly other perceptual senses can also be engaged. This visual information is used to make sense from the virtual environment, just as it does in the physical world. However, virtual reality goes beyond the physical world in some ways. Natural physics need not necessarily apply, nor do natural modes of perception. We have the possibility of exploring the environment as both an emerging aesthetic and as a practical test-bed for development of ideas and relationships (Gigliotti, 1995). As stated by Mones-Hattal and Mandes (1995):

> The primary purpose of most current virtual environments is to create a modeled duplicate of reality. For an artist, the ability to extend or manipulate our sense of physical reality and not simply duplicate it is an opportunity to expand our ways of seeing, feeling and experiencing, far beyond what we can do in our ordinary lives. There is really very little reason, especially in the context of art, to refine virtual worlds to the point where they are indistinguishable from reality especially when we can find ways to share what we can imagine with each other. (p. 890)

2.3.3.1. Metaphysics of Virtual Reality

Virtual reality (VR) is, as Beardon (1992) describes it "a simulation in which we are invited, or perhaps persuaded to amend our belief in what is real." It is a means by which to experience alternate views of both physically real and imagined environments. By combining the power of computing technology and advancements in human-computer interface design, virtual reality provides a metaphorical parallel to our real-world analogue, and forces us to ask deep questions about our traditional understanding of metaphysics, such as 'Where is *here*? Is it the location of my physical or my cognitive/emotional/spiritual being? And who am *I*? Am I what I am *here*, or what I purport to be *there*? Or both? And how do *I* relate to everything else that I am experiencing?

The technology has turned our traditional view of metaphysics on its ear. What we have come to know as perceptibly real is now completely manipulable; the knowledge and process associated with developing meaning within this new rubric completely rocks our assumptions of real, unreal, false, true, signifier, and signified (Nöth, 1990). Our frame of reference, as Einstein so elegantly stated, is truly relative. And, as Gigliotti (1995) and Krueger (in Heim, 1993) point out, "these are aesthetic questions with engineering consequences."

As described by Chesher (1995), at issue is our understanding of *signifier* and *signified,* our concept of metaphor and what it represents (Lakoff & Johnson, 1980). This relates directly to sign and object, as described by Cunningham (1992). The relationship between what we are referencing, the symbols used to represent what we are referencing, and the "relationship in the mind" (Peirce, 1955) is infinitely iterative. The referent can be infinitely referenced, creating a series of very deep interrelationships and constructs. Imbedding meaning-within-meaning becomes fractal in a sense. One can travel both forward and backward along the referential path, expanding or contracting one's knowledge structure as need be. This correlates strongly related to Shank's (1992; Shank et al., 1994) description of abductive reasoning, as illustrated in Figure 2, in that the individual iterates between idea, hypothesis and experience.

The relationship between signifier and signified is further discussed by Baudrillard (1983). A *representation* is a model of that which is signified if I never lose my belief that it is the original object that is the real object, rather than the representation. In a *simulation*, the signifier may not have a direct referent to the "real" world, nor is one required. The model, or signifier, takes on a reality of its own. This further describes the sensation of "presence". (Hoffman, Prothero, Wells & Groen, 1996; Winn, Hoffman & Osberg, 1995), in which one is convinced that the virtual world is real.

To describe how the aesthetic, corporeal, and intellectual processes can be engaged through representation in virtual reality, four examples of non-traditional environments are provided. None of these environments could have been created without the aid of virtual reality.

2.3.3.2. Four Non-traditional Environments

The potential to explore virtual space and make meaning from it in a very non-traditional perceptual manner has perhaps best been embodied to date in the works of Brenda Laurel (Placeholder), Char Davies (Osmose), Margaret Dolinsky (Dream Girls) and McCagie Brooks Rogers (Mythseeker). These projects demonstrate the extensibility of the technology by illustrating places that virtual reality can take us, but that traditional simulations cannot.

In *Placeholder*, Brenda Laurel uses Native American legends to explore the boundaries of representational art and environmental backdrops, allowing participants to "become" the personification of one of four petroglyphs (crow, spider, fish or snake), and to share their experiences with the narrator and another participant. The environment allows the participant(s) to experience the world from the perspective of the personified animal, as opposed to their traditional (human) perspective.

In *Osmose*, Char Davies has created an ethereal, surreal environment in which navigation takes place through breathing. The interface to the environment is a chest sensor, that tracks the participants' breathing to control movement. As one inhales, one rises, as if scuba-diving. This is one of the most spectacular representational and experiential art forms ever presented that maximizes the capabilities rather than the hindrances of the technology to date.

Margaret Dolinsky is a visual artist and virtual environment creator at the University of Illinois at Chicago. In her work *Dream Girls*, there are many representations that women in her milieu wanted to include as part of a girl's "dreams." It is a wonderfully colorful yet mystical place, where one can gateway to a number of different personal dream representations by entering a virtual head or other representational object present in the environment.

This mystical component of virtual reality is enhanced, and also made more educational in an environment called *Mythseeker*, created by McCagie Brooks Rogers. In this virtual world, participants can explore the cosmology of six different spiritual systems: Christianity, Shakti, Shamanism, Kabbalah, Greek Mythology, and Indian Mythology. The purpose of this environment is to provide the participant with the opportunity for self exploration, deepening of spiritual connections and personal meaning making by experiencing the symbology, rituals and relationships within six different cosmologies. The Mythseeker project's sole purpose is to provide a means by which individuals can explore, at their leisure and within the privacy of their own virtual domain their beliefs, fears and hopes for personal and spiritual growth.

What these four environments have in common is the highly experiential component; all of them are deeply interactive and are designed to give the participant(s) a strong sense of presence in an alternative space. With the exception of the Mythseeker project, they are not *directly* intended to be intellectually educational. However, they provide an alternative design framework that goes beyond traditional use of the technology, and are therefore useful examples for future application to education.

2.3.3.3. Visual Thinking and VR

The potential for developing and experiencing virtual environments as a learning tool is possible due to our changing educational values. As we come to better understand the nature of human intelligence, creativity, and the value of being multi-modal in our perceptions and our productions, there seems to be an increased awareness of developing our children's *visual thinking skills* in addition to the more traditional focus on reading and writing. Because we can create environments whose properties may have no parallel in reality, we can begin to stimulate children's imagination and visual thinking processes.

When students build virtual worlds, this visual thinking process is clearly demonstrated through the selection and representation of key elements necessary to create meaning in the environment. These elements are displayed both through visual interpretation and through interaction with the environment itself. This opportunity for developing what Gardner (1983) terms *spatial intelligence* can be fostered through virtual environment creation and experience. For instance, Mones-Hattal & Mandes (1995) describe the opportunity for creating and experiencing environments constructed using a 3D form of visual semantics:

> In other words, visual meaning is at least partially derived from the color, form, orientation, and movement of the visual target, and that these qualities are generally immediately apprehensible. Semantic syntax is dependent upon classes of symbols, combined according to a set of specific rules. Visual syntax uses spatial points as its sole class of symbols and is combined through spatial juxtaposition. Developing environments that display both representations and abstract components will provide for us a testing ground for unusual design opportunities and perceptual ambiguities. (p. 890)

The focus of virtual learning environment development, as with educational development of any kind, must start with at least the rudiments of what is *known*, and build from there. Metaphorical representation is a wonderful tool, but the environment must still be interpreted to have *meaning*.

Visual thinking deals with the holistic interpretation of the visual scene, rather than the linear interpretation of verbal or text-based materials. According to Solso (1994), visual thinking takes place in three stages:

4. The scene is analyzed for basic elements of visual stimulation; form, color, orientation, and movement.

5. Elements of contour perception, and figure-ground discriminations take place.

6. Forms perceived are given *meaning* from the individual's *visual memory*; the combination storehouse and visualization mechanism of mental imagery.

The active, conscious use of visual memory as a meaning-making tool is where the rubber hits the road in a cognitive sense. But how does this take place in the brain?

This section explores current research regarding the role of mental imagery and visualization in meaning-making, both in terms of representation and application.

The Mental Image

A mental image is the representation in the mind of a particular "aspect, concept, or referent" (Cunningham, 1992). Visualization is the process by which those mental images are created and utilized. The constructivist and the semiotician are interested in how these images are developed and used by the individual in terms of meaning-making.

Humans continuously seek meaning in the environment, in interactions, and in our own perceptions. What constitutes the process of meaning-making has been hotly debated for many centuries, starting with the first documented inquiries into the nature of the mind and of knowledge as represented by Plato, in describing his wax tablet metaphor in the *Theaetus* (Nöth, 1990; Kosslyn, 1981, 1994). Plato explored the notion that the quality and usefulness of mental representations can vary extensively from individual to individual, just as representations on a wax tablet can vary based on the quality of the wax, the clarity of the image, the skill of the image-maker, and so forth. Most cognitive psychologists today acknowledge an underlying assumption that humans (and perhaps other organisms) create and store images of some kind, both those that are meaningful (Duffy & Jonassen, 1992; Cunningham, 1992), and those which are superfluous.

Mental images are important, because they contribute to the way individuals understand relationships (Morris & Hampson, 1983). Text or verbally-based information that is connected to a visual memory is often more memorable (Samuels & Samuels, 1975). This study describes the use of virtual reality as a tool to enhance the visualization process. By listening to discussions among students during their design process, it was clear that students made connections between visual representations and verbal memory. By enhancing the visualization process, students may have greater access to information in multiple formats, enhancing the richness and recall of that information.

Constructing Mental Images: Three Perspectives

Paivio (1971) developed the dual coding theory of cognition. In his view, all perceptual information is translated into one of two modalities; verbal, and non-verbal (primarily pictorial). As stated by Ernst (1983), in describing Paivio's work:

> The verbal system was viewed as being specialized for dealing with relatively abstract information, such as language whereas the specialization of the imagery system was processing concrete perceptual information, such as non-verbal objects or events (p. 1).

Based on Paivio's (1971) extensive experiments in this area, it became apparent that perceptions and memories of perceptions also varied in vividness, depending on the type of image that was generated for the individual. At the cellular level, perception activated first-order cells, as well as higher order processes, whereas memories only activated second-order and higher level processes, losing the first-order properties that would "give it the completeness and vividness of perception" (p. 477).

In work completed by another of Paivio's colleagues, Katz (1983) mentions the effect of culture and personal experience in combination with individual differences as a source of image quality. In his view, variations in imagery proficiency may be "regarded as symbolic habits resulting from different patterns of experience" (p. 51). In addition, metacognitive strategies are also seen as a component of imaging proficiency, in that "individual differences in imagery will not emerge unless people first realize that imagery processing is called for" (p. 52). In other words, high imagers may be those individuals who have not only native ability, but the metacognitive skills to know when to apply image processing strategies. The driving motivation behind all of this, in Paivio's view, is to make the most sense out of the environment at the least cost. Therefore, information is stored in either form, or both, in the brain.

In contrast, Pylyshyn (1981) sees part of the problem in describing one's mental images and how those images are represented as a semantic issue. For example, it is often difficult to accurately describe with words a pictorial process or representation. When we report about our experience, we are indeed limited to our language at hand to describe that which is not a language-based experience at all. Chomsky (1964) noted this disparity in our limited ability to communicate about such experiences as a lack of "explanatory accuracy."

The last perspective on mental image development is presented by Pinker & Kosslyn (1978). In their seminal work *The Representation and Manipulation of Three-Dimensional Space in Mental Images*, Pinker & Kosslyn (1978) state quite strongly that indeed the images that a human chooses to represent and to analyze are "potentially rich in detail, spatially correct, and accessible for mental manipulations such as rotation and inversion" (p. 72). This is in opposition to the position taken by Pylyshyn.

Kosslyn's (1981) focus on function helped him to build a working computer model of the development and application of imagery. This model is based on what Kosslyn calls the "Cognitive Theory of Imagery", and represents a description of the visual system's *structures*, both data and the communication medium, and *processes,* or those actions performed on the data structures themselves.

Data structures are those components of one's understanding that describe "format, content, and organization." In this case, Kosslyn (1981) develops the underpinning of Cunningham's later view of symbol development by stating:

> The *content* is the information stored in a given data structure. Any given *content* can be represented using any number of *formats*. For example, the information in the previous sentence could be stored on a magnetic tape, on a page, as a series of dots and dashes etched on metal, and so on. The *organization* is the way the elementary representations can be combined. The *format* of a representation constrains the possible *organizations*, but does not determine them.

Cunningham (1992) takes the notion of reorganization based on context much further in his theory of an educational semiotic, as discussed in section 2.1.2.

These three views have been presented to illustrate the variety of perspectives on the value and application of images. In this study, students were encouraged to visualize during their design process. Part of the world building exercise required students to reframe or convert information from text to visual images, and to do so in a meaningful way. The translation between formats (text, verbal, visual and auditory) was critical to the students' successful design and development of a virtual environment (Dickson, 1985). It has been found that "conceptual framework data and information can only be potentially meaningful, not *intrinsically* so" (Winn, Hoffman & Osberg, 1995). Visualization was used to assist students in making the content they studied meaningful.

Using Mental Images

Morris & Hampson (1983) state that consciousness is an integral part of one's awareness of the imaging process. Conscious actions that affect the imaging process include:

- Perception of the external world.
- Introspection
- Ability to focus attention in a particular manner.

Mental images can be useful tools for cognition. According to Morris & Hampson (1983), there are three dimensions of individual perception upon which images vary:

1. The intentional/passive role of the individual in the creation of the image

2. The experience of the image as being out there as part of the real world, or existing internally in a different form from real objects

3. The belief that what is being experienced is part of the real world, or is created in some way by the individual's mental apparatus (p. 65).

In Morris & Hampson's (1983) view, all perceptions are colored by past experience, and by the mental schemata in place at the time of perception (Ryle, 1943; Neisser, 1967; Johnson-Laird, 1980). Therefore, conscious imaging can encompass a broader range of possibilities than random imaging.

2.3.3.4. Summary

In this section, the visual perception aspects of virtual reality have been explored. Four alternative environments that set the benchmark for effective use of virtual technology were presented, followed by a discussion of the relationship between visualization and virtual reality. Conscious imaging was presented as a preliminary exercise to virtual environment design, supporting mental manipulation of images that were then translated into virtual representations.

In the next section, practical aspects of integrating virtual reality technology into the curriculum are explored.

2.3.4. VIRTUAL REALITY AND EDUCATION

2.3.4.1. Constructivism and Educational Technology: An Overview

There is a natural linkage between the constructivist learning paradigm and the utilization of educational technology in the classroom (Duffy & Jonassen, 1992; Saloman, Perkins & Globerson, 1991; Scardamalia, et al., 1989) . Today's computer systems can be used to "communicate, create, inquire, categorize, synthesize and present" (Zemelman, Daniels & Hyde, 1993) information. They are an excellent storage and manipulation device for both existing information, and for one's original ideas and creative work. They therefore serve as tools that allow students to build their own mental models. By definition a symbol processing system, computers can also be used to transform information from verbal and digital forms to visual, auditory and haptic representations. As such, the use of computers in the classroom can be a powerful adjunct to teaching and learning for students and teachers alike.

Duffy & Jonassen (1992) feel that today's practice of educational technology should indeed be couched in the constructivist paradigm. This plays out in terms of developing systems that are situated in the real world as much as possible and are as experiential as possible. The goal is to design and present authentic learning opportunities in which individuals have the freedom and the opportunity to ground their experience in a manner appropriate to them.

The individual engaged in learning should have the opportunity to inquire, and to develop understanding from their own and others' perspectives when constructing knowledge. This position is supported by the work of Cunningham (1992), Belenky, et al.*,* (1992), Noddings (1984, 1993), Adams (1989) and Adams & Hamm (1988), who report the effectiveness of this approach for helping students learn.

2.3.4.2. Bridging the Gap Between Multimedia and Virtual Reality

Computer technology that has been integrated as a learning tool into the body of the curriculum can have a very positive effect on student motivation, engagement, and learning (Dwyer, 1994; Taylor, 1992). This is especially true of those technologies that require the student to actively engage with the information presented (Perkins, 1993; Winn & Bricken, 1992; Byrne, 1996). As the constructivist learning theory describes, learning-by-doing appears to be a key factor in content assimilation and retention, and in student enjoyment. (Brooks & Brooks, 1993; Minstrell, 1989; Lochhead, 1988; Winograd & Flores, 1986).

Interactive technologies that are in use in many classrooms today include multimedia and the Internet. The effects of these two technologies has been felt deeply within the educational community. (Spiro et al., 1992a, 1992b). Due to their design, these technologies are alternatives to the linear structure to much information presentation, facilitating a more broadly defined, amorphous data gathering technique that is again supportive of constructivist learning principles (Dede, 1990, 1992; Papert, 1993; Lochhead, 1988).

Two Internet-based examples are the JASON project (Ballard, 1992; Baer, 1989), a science and engineering web-site where students can interact with the terrestrial and ocean environments telerobotically, and Toy Scouts (Companion et al., 1995), another interactive web-site that students can visit and study. These are representative of the kind of multimedia environments that 'bridge' between single-computer CD-ROM based systems and multi-participant environments. The next step, just a dimension away, is to move into virtual environments for education and training (Dede, 1992, 1994; Dede, Salzman & Loftin, 1996), which will be discussed in the next section.

2.3.4.3. Virtual Reality as a Constructivist Learning Tool

The concept of "learning by doing" (Bruner, 1990) is certainly not new; however, allowing the student to learn by doing within the classroom context is a departure from traditional methods; one which virtual reality enables (Lewis, 1993; DeVries, 1995). As an experiential learning tool, virtual reality is an enactive knowledge-creation environment. In this study, each environment we developed contained a combination of real-world analogs and abstract representations, providing students with an opportunity to learn and to share information with others.

Houser (1987) describes three types of signs: icons, indexes, and symbols. All three types are found in virtual learning environments, and are important for their unique contribution to the meaning-making process. Icons, the signs most analogous to their real-world referants, are important for populating the environment with recognizable objects that "ground" the student in context. From that context, indexed and symbolic objects take on meaning in relation to iconic and spatial representations present in the environment. There is no value associated with one sign over another; it is how the environment functions as a whole that is important.

Virtual Environment Construction vs. Experience

There are two distinct aspects to the use of virtual environments as a learning tool: the actual *construction* of a virtual environment, and the *experience* of visiting a virtual environment. The construction process involves developing an understanding of the objects, relationships, interactions, aesthetics, ethics and interface issues inherent in the finished product (Gigliotti, 1995), which requires the selection or creation of icons, indexes and symbols. It is primarily a creative and intellectual process; one in which the virtual artist attempts to create a meaningful space that can later be experienced. Experiencing a virtual environment, on the other hand, involves using one's body and mind in conjunction to make meaning from the experience of visiting the virtual space, without perhaps having had the opportunity to design the space being experienced, and requires just the use of icons, indexes and symbols. It is primarily a visceral and intellectual process. In both cases, designer and experiencer, the individual has the opportunity for meaning-making; for learning from the process itself.

However, the integration of virtual reality in the classroom, whether as a design process or as an experiential learning tool, is still in its infancy. Though some research has been conducted (Winn, Hoffman & Osberg, 1995; Merickel, 1992; Byrne, 1993, 1996; Osberg, 1993a; Rose, 1996), there is interest in learning much more about both the world-building process and how it relates to meaning-making, and the educational value of world-experiencing process (Rose, 1996; Winn, 1992). Furthermore, there is great interest in making the most of what we bring to the learning process in the use of virtual reality (Norman, 1993; Bowers, 1988, 1992; Osberg, 1993a), instead of focusing on the flash and dazzle of the technology itself.

Virtual reality goes at least one level above multimedia in terms of perceptual richness and locus of control. The primary difference is in intent; multimedia is a *representation*, whereas virtual reality is a *simulation*, intended to fool the senses into believing that the participant is perceiving their 'physical' body to be in another place. And yet, it is the reintegration of the body in the search for knowledge that provides such a compelling *tour de force* to the technology, as described by Heidegger's (1977) notion of being 'ready to hand', i.e. accessible for scrutiny and unmediated use. This last point is particularly powerful in education. By bringing our bodies back into the search for meaning, we can at long last become fully, not just intellectually, integrated.

All of what we experience is a construction of sorts (Duffy & Jonassen, 1992; Winn, 1992) in that all communication, both internal and external, is mediated to a degree. Indeed, one can think of VR as a three-dimensional Rorschach test, in which the need for interpretation is implied, if not required. This places the technology more as experiential and interpretive informational art rather than as a direct means of deriving objective meanings and truths. This point is similar to the one made by Heidegger (1977), in his postmodern view of communicative technologies in which he states "reality changes, and with it the task of thinking".

2.3.2.4. VR in the Classroom: Practical Considerations

Much of what has been described thus far with regard to VR and education has painted the technology and its application in the classroom in a very positive light, and research has indicated that there is indeed perceived value to be had (Dede, 1992, 1994; Dede, Salzman & Loftin, 1996; Loftin, Engelberg & Bebdetti, 1993; Loftin & Kenney, 1995; Byrne, 1996; Winn, 1992, 1997; Osberg, 1993b). However, the *practical* side of virtual reality as a learning tool has two components: access and appropriateness. Both need to be more substantively addressed if VR is to actually become a practical reality in the classroom.

Access to the technology requires that it be available, and that cost is not a prohibitive factor. Another form of access has to do with interface design. The technology must be made available and accessible to the user from a cognitive, physical or affective sense. Otherwise, individuals may be precluded from utilizing the technology due to complexity, knowledge barriers, or physical barriers.

Industry has hyped virtual reality and nearly all other computer-based learning technologies as the next educational panacea. Such an expectation is unwarranted and inappropriate. As described by Dennen & Branch (1996), in some respects this technology is the prototypical "technology looking for a purpose". However, based on our research, we find there are excellent applications for virtual reality as a learning tool, primarily those that require high visualization skills or 3-D representations, present abstract information in a more cognitively accessible format, or present the opportunity for experience which cannot be had any other way. (Osberg, 1992; Byrne, 1996; Winn, 1997).

This section describes how this technology might be used in the classroom. Support for computer-mediated instruction as a constructivist learning tool was presented, including virtual reality technologies. Distinctions were made between virtual environment construction and experience.

2.4. SUMMARY

In this chapter, the conceptual framework for this study was presented. The process of making connections between signs, symbols and relationships was discussed in the section on constructivism. Peirce's (1955) traidic model of sign was presented as the basis for exploring relationships between signs, referents, and objects. Virtual reality was then presented as a constructivist learning tool to assist students in making deep, meaningful knowledge constructions in a visual, auditory and interactive environment.

Based on the above relationships, I designed and conducted a study that implemented a constructivist approach to learning, as mediated through 3-D interactive environment construction and experience. In the following chapter, research methods are presented.

CHAPTER 3: METHODOLOGY

3.1. RESEARCH HYPOTHESIS

Middle school students studying wetlands ecology using constructivist learning strategies, including virtual environment design and development (Treatment 1) will demonstrate significantly better content assimilation and retention, develop more extensive mental models and experience greater learning enjoyment as measured by a multiple choice quantitative assessment tool, a concept mapping exercise, an attitude survey and analysis of their performance in the virtual world when compared to those students using traditional learning strategies (Treatment 2), and a no-instruction control (Treatment 3). Subjects who experience Treatment 2 will demonstrate significantly better content assimilation and retention, develop more extensive mental models and experience greater learning enjoyment as measured by a multiple choice quantitative assessment tool, a concept mapping exercise, an attitude survey and an analysis of their performance while a virtual world compared to those students who received no instruction (Treatment 3; control). The control group's content assimilation will be measured by a multiple choice quantitative assessment tool, a concept mapping exercise, an attitude survey and an analysis of their performance while in a virtual world.

3.2. PROCEDURES

3.2.1. SUBJECTS

Subjects in this study were 117 middle school students attending Kellogg Middle School in north Seattle. These students were almost evenly split between grades 7 and 8, and ranged in age from 12-14. Intellectual development ranged from learning disabled (3 students suffering from either dyslexia or ADD) to slightly brighter-than-average, though the bulk of the student population would have been considered typically developing. Of the 117 students, 56 were girls, and the remaining 61 students were boys. The student population for this study was derived from the school's natural catchment area, though they were self-selecting based on the program option selected at the beginning of the school year. Students who selected KCOT as their program option were expected to stay within the program for both grade 7 and 8.

The class cadres to which these students were normally assigned were temporarily suspended for the duration of the project, to allow their teachers to randomly assign the students to four groups: Carbon (n = 30), Energy (n = 27), Nitrogen (n = 30), and Water (n = 30). The group name represented the wetland cycle that each group of students constructed . Three students who were originally in the Energy group left the project after assignments had been made, due to lack of parental approvement of their participation. Rather than re-assign students again, the KCOT teachers elected to keep the groups as they had been originally constructed. These three students studied with the No Instruction control teacher for the duration of the project.

These students were part of a 4-classroom experimental program known as ACOT/KCOT. As an ACOT (Apple Classroom of Tomorrow) classroom, there were computers located in the rooms where the students study and learn, rather than in a separate learning resource or library facility. KCOT stands for Kellogg Classroom of Tomorrow. The KCOT program utilizes constructivist learning principles including integrated multiple-content area curriculum blocks and the use of technology as an integral part of the learning process. The subjects were either individually (when in their own classroom) or team-taught (when two classrooms are combined) by two teachers per classroom. A further discussion of the KCOT classroom can be found in section 2.2.2.3. of this document.

For the purposes of this study, all four KCOT teachers were an integral part of the process as was an additional 'traditional' science teacher who temporarily came out of retirement to participate out of personal interest. The last individual involved in the project was Shoreline School District's Teacher Development Center (TDC) coordinator who doubles as the district's leading trainer on developing and maintaining a constructivist classroom that integrates technology into the curriculum.

3.2.2. DESIGN

Students in each of the four groups:

- Studied, designed and built the virtual environment associated with their group
- Studied two of the four cycles using traditional instruction strategies
- Received no instruction on one of the wetland cycles

The classroom is a dynamic, ever changing environment. In theory, a four-group, four-treatment analysis had been designed for each of the wetlands cycles that incorporated experience in the virtual environment as part of the treatment program. In practice, the data collected required changes to the original design as stated in the research hypothesis, which allowed for some very interesting alternative analyses. Due to the need to provide instruction in three out of four wetland cycles in the short time span allotted for the project coupled with the fact that the teachers felt that the carbon and nitrogen cycles were more educationally important than the energy and water cycles, the four-treatment research program became unfeasible. Therefore, the three-treatment program was developed.

A post-hoc analysis comparing students who both built and experienced their virtual learning environment to students who built but did not experience their environment was also conducted. This was possible because 21 students DID NOT experience virtual reality due to absence on the days the technology was available, though these students still provided both quantitative and concept maps data. This unexpected occurance led to the opportunity to conduct analysis specific to the value of the virtual experience.

The treatments, based on instructional strategies, were:

- Treatment 1 (T1): Constructivist learning (including world building)
- Treatment 2 (T2): Traditional instruction
- Treatment 3 (T3): No instruction

Data sets for 88 out of 117 students were retained for statistical analysis. The other 29 were too incomplete to be of value. Of these 88 students, 47 were boys; 23 of which were 7th graders and 24 8th graders and 41 girls; 21 of which were 7th graders and the remaining 20 8th graders. Not all students had complete data sets (quantitative, concept map, interview and survey data), but all 88 students had complete scores for at least two of the four measures.

This project was the pilot for the Virtual Reality Roving Vehicle project and was the basis from which we developed our extended research program. As the pilot, this opportunity was used to develop a better understanding of how world-building functions as a meaning-making process and how to effectively integrate virtual reality technology into the curriculum as a learning tool. In support of these activities, I wrote a Teacher's Manual on Virtual Environment Development, and designed a 4-step (Planning, Modeling, Programming, and Experiencing) world-building process that expanded upon findings from research conducted in previous world-building exercises (Osberg, 1993b; Byrne, 1993, 1996; Bricken & Byrne, 1992). This world-building process is described in section 3.2.3.1. of this document.

The subject area studied was wetlands ecology. Within this subject area, four cycles were studied: carbon, energy, nitrogen and water.

The constructivist learning paradigm was paired with the virtual environment creation process as part of the learning paradigm. Students in the constructivist treatment chose their own source materials from the library, the Internet and from district resources. In contrast, students in the the two traditional cycles studied using textbooks and worksheets in a teacher-directed classroom environment, though they had the option to find and use alternative information sources if they so desired. The last cycle was not studied, and served as a means to test the assessment instruments.

All subjects were pre- and post-tested by having them draw concept maps (pictorial/verbal representations of the individual's view of that particular cycle) and by a multiple choice instrument that addressed all four cycles. Both assessment tools were designed by the KCOT teachers in conjunction with the visiting science teacher.

As an example, the relationship between instructional strategy and type of information access for the Carbon group is presented in Table 3 below.

Table 3 - Single Group Instructional Strategy
Example

Group: Carbon	**Cycle**	**Instructional Strategy**	**Information Access**
	Carbon	Constructivist	Model design & construction, Internet, Self-selected Materials, CD-ROM's, Textbook
	Nitrogen	Traditional	Textbook, Worksheets, Self-selected materials
	Water	Traditional	Textbook, Worksheets, Self-selected materials
	Energy	None	None (though some cycle content overlap occurs)

The KCOT teachers decided that all groups should have the opportunity to directly study the nitrogen and carbon cycles. The energy and water cycles were considered of lesser educational importance since these are cycles that are often studied in general biology courses. Therefore, the more educationally intensive treatments were assigned to the more 'important' cycles; nitrogen and carbon, with the energy and water cycles studied either in the traditional classroom, or as the no instruction control except for in the case of the two groups who created each of those virtual learning environments. The lesser value placed on the energy and water cycles can be clearly seen in Table 4, below, a matrix illustrating the instructional strategy for each of the four groups for each of the four wetlands cycles.

Table 4 - Group by Treatment Matrix

Group	**Constructivist Paradigm + World Building (T1)**	**Traditional 1 (T2)**	**Traditional 2 (T2)**	**No Instruction (T3)**
Carbon	Carbon	Nitrogen	Water	Energy
Energy	Energy	Carbon	Nitrogen	Water
Nitrogen	Nitrogen	Carbon	Water	Energy
Water	Water	Carbon	Nitrogen	Energy

3.2.3. PROCEDURE

The study lasted two weeks, 4 days a week on site at Kellogg Middle School. There were two 1.5 hour blocks per day of teaching time in the KCOT classrooms, from 9:00 - 11:30 and from 12:00 - 1:30. During each of these blocks, each of the four classrooms were held class simultaneously: one in virtual environment development and constructivist learning, one on traditional science, and two on other subjects currently being studied that were note wetlands-related.

For constructivist learning and world building, students had a total time-on-task of 6 hours, 3 hours per week. The same held true for each of the other cycles except for the no instruction control. All testing was conducted either before the project began or after completion of the project. This meant that almost all classroom time could be spent on-task.

The amount of time spent in each activity was the same for each of the four groups. Using the Carbon Group illustrated in Table 4 above as an example, their time was spent in the following manner:

- Constructivist classroom time: Self-directed study of the carbon cycle, designing and building the virtual Carbon World
- Traditional classroom time: Teacher-directed study of both the water and nitrogen cycles. No classroom time was spent studying the energy cycle.

Table 5, below, illustrates the amount of time spent in each treatment for each group. All blocks represent 1.5 hours of time.

Table 5 - Time-on-Task in 1.5 Hour Blocks for each Treatment

WEEK ONE	**Monday**	**Tuesday**	**Wednesday**	**Thursday**
Constructivist Morning (T1)	Water	Nitrogen	Water	Nitrogen
Traditional Morning (T2)	Energy studying Carbon	Nitro studying Carbon	Energy studying Carbon	Nitro studying Carbon
Constructivist Afternoon (T1)	Carbon	Energy	Carbon	Energy
Traditional Afternoon (T2)	Carbon studying Nitro	Water studying Carbon	Carbon studying Nitro	Water studying Carbon
WEEK TWO	**Monday**	**Tuesday**	**Wednesday**	**Thursday**
Constructivist Morning (T1)	Water	Nitrogen	Water	Nitrogen
Traditional Morning (T2)	Energy studying Nitro	Nitro studying Water	Energy studying Nitro	Nitro studying Water
Constructivist Afternoon (T1)	Carbon	Energy	Carbon	Energy
Traditional Afternoon (T2)	Carbon studying Water	Water studying Nitro	Carbon studying Water	Water studying Nitro

3.2.3.1. Constructivist Instructional Program

During the first 1.5 hour constructivist block and half of the second 1.5 hour block, Carbon Group subjects had the opportunity to look over materials related to general wetlands ecology and the carbon cycle specifically. These materials were selected by the students from library guides. They could also view Internet-accessible information on wetlands ecology and their particular cycle, review CD-ROM and video-disk materials about the process, and develop an understanding of the concepts based on their experiences with these materials. There was no direct instruction in the constructivist classroom.

During the second half of the second 1.5 hour block, subjects met in groups of 10 led by a Human Interface Technology Laboratory (HIT Lab) Virtual Reality Roving Vehicle (VRRV) representative. In these groups, students assumed roles to make certain that all aspects of the design/build process would be covered, and to provide students with a sense of self-authority and responsibility. Roles were selected by the student. Two student per group were allowed to assume each role. These roles were:

- Project Facilitator (Project management and overall organization)
- Cybrarian (Documentation of the project, document management)
- Base Modellers (Creators of the base world in which all other objects were placed)
- Art Directors (In charge of composition and aesthetics of the environment)
- Behavior Designers (In charge of interactive components within the environment)

After roles were assumed, subjects discussed their view of what should be contained in a virtual wetland environment designed to portray the cycle that they were studying. Each group of 10 students designed their environment from the ground up. The design process included:

- Developing an understanding of the educational value of the environment and establishing learning objectives
- Defining the objects to be placed in the virtual environment
- Drawing sketches of the objects to be created on the computer
- Defining the behaviors, interactions and events inherent in the environment by creating a Behavior Matrix.
-

During the third and fourth 1.5 hour blocks each subject created their set of assigned objects on their classroom computers, either alone or in groups, using Swivel 3-D and a MacIntosh computer as their modeling tools. I constructed the final virtual environment from the students' objects, drawings, and behavior matrices, on the Division ProVision 100, a proprietary system including both the programming/rendering language and virtual reality hardware.

The World-building Process

With any new technology, there is the need to foster new ways of working with the system. Regarding the development of educational virtual environments, a system to rapidly empower both the teachers and students needed to be developed, allowing them to be relatively self-sufficient and to use the technology to its best advantage.

The reasons for this were two-fold:

7. As Constructivists, the teachers and students needed to have as much hands-on control of the process as possible for their own sense of esteem, accomplishment, and empowerment.

8. The process had to progress without a HIT Lab staff member's presence.

I began writing a teachers guide (Osberg, 1995a) during the summer prior to the VRRV project that was used in subsequent teacher training programs. This document, entitled *A Teacher's Guide to Developing Virtual Environments* described the four-step process developed during previous and current world-building experiences with children (Bricken, 1991; Bricken & Byrne, 1992; Byrne, 1993, Osberg, 1993b).

Unfortunately, the publication was not available to the Kellogg Middle School teachers. Instead, HIT lab staff were present during the entire study to lead students through the world building process. By refining the process through the pilot study at Kellogg Middle School we were able to generate a much more comprehensive and helpful guide.

One aspect of the project that cannot be stressed enough is the need for effective project management. Building a virtual environment represents a departure from the way that classrooms are normally run even in the Constructivist environment at Kellogg. Students needed time to become proficient at creating 3-D models, to design and develop their ideas about the environment and interactions in the environment, and time to work together as a group. An example of the kind of time commitments required for these activities, based on the four-step process and our experience at Kellogg Middle School is presented in Table 6, below.

Table 6 - Schedule Development for Virtual
Environment Development

PROJECT ACTIVITY	**PERFORMED BY:**	**TIMELINE MINIMUM**	**FUDGE FACTOR**	**DESIRED OUTCOME**
3-D Modeling Training	Teachers Students	6 hours 6 hours	± 4 hours ± 4 hours	Proficiency Proficiency
Process Planning	Teachers	4 hours	± 2 hours	Overall Guide
World Planning	Students & Teachers	6 hours	± 4 hours	World Plan
Constructing	Students	4 hours	± 2 hours	Workable objects & environments
Programming	Students	3 hours	± 2 hours	Completed Behavior Matrix
	HITL Staff	2 days	3 days	Completed World
Experiencing	Teachers Students	TBD	TBD	Solid understanding of the created environment

In this pilot study, the four regular classroom teachers took part in all aspects of Process Planning. They were in charge of logistics, schedules, selecting student groups and the wetland cycles to be studied. After these decisions had been made, HIT Lab staff took over and taught students the four-step world building process, starting with World Planning.

The Four-Step Process

The four steps or phases of world building are Planning, Building, Programming and Experiencing. By providing a progressive structure to the process, students had ample opportunity to think deeply about their constructions and to enhance their visio-spatial skills through drawings and models created both by hand and with the assistance of the computer. These four steps, as they relate to the Kellogg Middle School project, are described below.

Planning

During the Planning phase, KCOT teachers selected the wetland cycles as the content to be studied. Subsequently, students and teachers worked together to choose an appropriate educational theme relevant to the curriculum being studied. During the Process Planning portion of the project, teachers were expected to develop the following:

- Curriculum Plan, including:
    - Selected subject/concept area
    - Educational goal and sub-goal statements
- Assessment Plan
    - Content assessment tool information
- Process Plan, including:
    - Project Timeline
    - Logistical Description
    - Student Teams/Student Schedules
    - Responsibility Matrix for all involved staff
    - Contingency Plan (what to do when everything imaginable goes wrong)

Once Process Planning was completed, World Planning commenced. HIT Lab staff, teachers and students brainstormed about the curricular theme, and about information that could be visually and interactively conveyed through the virtual environment.

As is true in any design process, there are innumerable ways that one can choose to represent a subject, process, or interaction. Based on the triadic sign model, students were asked to evaluate their selections based on their value systems and on their previous experience with objects and relationships within a wetland. Discussions covered how and why students chose certain objects and interactions. Though sign theory or the triadic model was not presented in the classroom, students talked about their reasons for selecting certain objects within their groups. Certain objects were used as "window dressing" to create an analog to a real wetland. Other objects were used to reference real-world objects more obliquely. Part of the value of virtual environment design is to come up with virtual representations that have consensual meaning. It was interesting to note that some of the children's inclusions were strongly cultural. For example, one student wanted to include a basketball as part of the carbon cycle, and another a tire representing pollution.

The World Plan was designed to assist teachers and students through the design process. It describes the environment as a whole (similar to developing a stage setting for a play), each individual object within that environment, who will be making it, how they will fit together and the behaviors in the environment, both object-to-object and participant-to-object.

The activities associated with developing a World Plan include, but are not limited to: brainstorming, developing thumbnail sketches, clay or other sculptural models and storyboards. Teachers and students were encouraged to get as deep an understanding about the environment as possible before breaking into individual groups to create their virtual objects on the computer. We found that having a picture of the environment as a whole and understanding its' educational purpose enhances the experience portion of the project substantially. Students chose which types of models they wished to create. At minimum, thumbnail sketches in 3 views (top, side and crosssection) were required before getting on the computer.

In the first part of the World Planning process, the selected subject/concept was expanded upon by brainstorming about the kind of objects that might be included in the environment, how the environment itself may look and feel and how the students perceive that the educational goals can be met through developing a presentation in this medium.

The environment was discussed in terms of its functionality, educational purpose and content. Student discussions focused on the environment as a whole and on the part-to-whole relationships. In this way, students began to 'ground' their understanding about the wetland environment in a very personal way by evaluating their own beliefs, existing mental models about the wetland and by incorporating new knowledge into these models.

Sketching and modeling were also encouraged. Sufficient although limited time to talk and develop ideas within their groups was provided. Visual representations, metaphorical concept representation and stage setting and design were discussed.

The Object Matrix

The Object Matrix was the first document generated from the brainstorming and modeling session. In it, students wrote out the final object 'list', prioritized the objects on it and assigned responsibility to a team member for each objects' creation. An example of an Object List taken from one of the Kellogg Water cycle wetland environments is illustrated in Table 7, below.

Table 7 - Object Matrix Example

INDIVIDUAL: ------------------------- OBJECT:	**OBJECT RATING (H, M, L)**	**JOHN**	**MEGAN**	**JOSE'**	**JANICIA**	**BRUCE**
SUN	H					X
SUN'S ENERGY	H			X		
LAKE	H	X				
CLOUD	H				X	
VAPOR	H	X				
RAIN	H		X			

The Behavior Matrix

After the Object Matrix was completed, students began considering the behaviors or interactions associated with those objects. It is never too soon to consider the environment as a whole and how the participant and the environment will interact with one and other.

"Behaviors" are events that can be assigned to an object in an individual fashion (i.e. are inherent to the object, and are not 'caused' by the participant or another object), and those to which a clear cause-and- effect relationship can be established.

The behavioral characteristics that can be assigned to an object or object-interaction are listed in Table 8, below.

Table 8 - Behavioral Characteristics for Object Interactions

INHERENT CHARACTERISTICS	CHANGE-IN-STATE CHARACTERISTICS
BASICS: POSITION, ORIENTATION, ORIGINAL COLOR, SCALE	CHANGE IN BASICS: POSITION, ORIENTATION, COLOR/APPEARANCE, SCALE CHANGE IN BACKGROUND COLOR
VISIBILITY	CHANGE IN VISIBILITY (VISIBLE/NOT VISIBLE)
COLLIDABILITY (COLLIDABLE/NOT COLLIDABLE)	CHANGE IN COLLIDABILITY (COLLIDABLE/NOT COLLIDABLE)
ORIGINAL SOUND STATE	CHANGE IN SOUND STATE
ORIGINAL MOVEMENT STATES (SPINNING/NOT SPINNING, PATHED/STATIONARY)	CHANGE IN MOVEMENT STATE: SPIN, MOVE BETWEEN OBJECTS
ORIGINAL PARTICIPANT PERSPECTIVE	CHANGE IN PARTICIPANT PERSPECTIVE (RIDE/UNRIDE)

“Collidability” is the property of being able to sense when the bounding box of one object intersects with the bounding box of another. A bounding box is a spatial encapsulation device that ensconces and defines the outer coordinates of a particular object. Interactions between objects who’s’ bounding boxes intersect are often used to visually present ‘cause and effect’ relationships. As an example from Nitrogen World, children chose to make both the cloud and nitrogen molecule “collidable”. When the bounding boxes of these two objects intersected, a rainstorm was ‘caused’ by that interaction.

Using the behaviors listed in Table 8 above, students began to think about what kinds of interactions or behaviors might be appropriate in their environment. From the brainstormed list, students developed the Behavior Matrix guide which was used as a programming aid when coding these behaviors during the Programming phase of the project.

Students learned that just because you CAN have an interaction doesn’t mean that you should. Interactions should add value to the experience and should be used judiciously. We suggested that they should, on paper, detail out each object and its' potential interactions for evaluation purposes but that these interactions needed to be prioritized in terms of their educative and interactive value. Each environment was limited to 10 interactions per 5 minute block, due to the time limit per student and the number of interactions that could be completed within that time frame.

Another limitation faced by students was the use of textures. Due to limited texture memory in the Division computer system, students were limited to 3 textures per environment. This made it difficult to come up with environments that were very realistic. Most looked very 'cartoony', with bright blocks of color associated with individual objects.

After all the types of interactions and textures available had been discussed, the next step the students undertook was to develop the Behavior Matrix. This matrix was limited to a 10 by 10 set of interactions. This constrained the number of objects that could be considered for interactions and also limited the kind of interactions that would be available under certain circumstances.

Students had the opportunity to explore different representations rich in visual or auditory *meaning,* including those attached to interactions that the students selected. For example, if students chose to provide energy from the sun to the blue-green algae, it didn't make sense to make the algae spin and change colors. However it might make sense to make the algae increase in size by either scaling or replicating it.

Interestingly enough, students immediately understood the concept of auditory feedback due to their experience with computers. Everyone understood the difference between sounds issued for errors, and those that connotated other actions. However, developing a sense of appropriate visual feedback was much more difficult for the children. In this respect, it was hard to get beyond the novelty factor of having the power to change almost any aspect of the representation at their command.

In Table 9 below is a partial illustration of the Behavior Matrix for the Water cycle used in Table 8, above.

Table 9 - Behavior Matrix

1st OBJECT: --------------------------- -2nd OBJECT:	**Sun**	**Sun's Energy**	**Lake**	**Cloud**	**Vapor**	**Rain**
Lake		Sound 'bong'; vapor on				When rain hits lake, lake gets deeper
Cloud					Sound 'bong'; rain on ; travels to ground	
User	Sound 'gong'	Sound 'ping'	Sound 'gong'	Sound 'gong'	Sound 'ping'	Sound 'ping'

Roughly translated, what is occurring above is happening at two levels: participant-to-object and object-to-object. During the participants' initial contact with an object, an auditory cue tells the participant whether the object can be 'grabbed'; all objects that are 'grabbable' have a higher pitched sound 'ping' attached to them. Objects that are not grabbable 'gong' the participant when touched.

When an object interacts with another object, for example the Sun's Energy and the Lake, the product of that interaction appears. In this case, the interaction makes the water Vapor appear. The auditory cue provided during the interaction is a medium-pitched sound (bong), telling the participant that the interaction has occurred. The visual cue of the appearing water Vapor provides additional reinforcement.

Additions to the World Plan

We suggested that students and teachers attempt to document their design process as much as possible, by making sketches, models and writing pseudocode snippets for the programming portion of the process. Other media, such as video and still photography and newsletter articles can also be used to capture this process.

Building

The Building component of creating a virtual environment is where the rubber hits the road, so to speak. Students learned that imagining is only half the battle.

Building what you see in your mind's eye is the other half of the relationship. The building process provided students with a means of making their imaginings concrete.

Object Construction

Students were encouraged to make paper-and-pencil sketches of their objects from three construction perspectives: top, side, and cross section views, as well as a combined view. These perspectives mapped to the Swivel 3-D software interface used to model the objects in 3-D. We found this type of analysis was *helpful* for simple objects and *critical* for complex, multi-component objects.

As an example, children found it relatively simple to make a straight cylinder. However, creating a virtual hand, comprised of many cylinders that must work in a certain fashion as a whole is a much more complex proposition. Though most students were quite capable even at the beginning of this phase of drawing (and modeling) simple objects, it took some tenacity and experimentation to figure out how to design and link objects to develop complex wholes. A dragonfly with independently manipulable wings is a good example of a complex object.

We found that asking students to mentally and physically take objects apart and reconstruct them in drawings from multiple perspectives was infinitely valuable to their understanding of the relationship between 2-D and 3-D representations. We were surprised at how their world view changed based on this activity. This was one of the most powerful aspects of virtual world design that we have encountered (Winn, 1995, 1997; Osberg, 1995b; 1997).

By visualizing objects from both the real and virtual environment in their mind's eye and on paper, students begin to understand that part-to-whole relationship and its relevance to modeling and on a grander scale as well (Samuels & Samuels, 1975, Richardson, 1980; Richardson, 1969, 1994; Kaufman, 1984). Students' language began to change. They spoke of whole-to-part relationships and on the value of multiple perspectives as a reflection of their world view. In addition, there is an amazing amount of power and latitude when it comes to describing and developing a "world". The sense of responsibility for developing an environment, especially a learning environment granted students an autonomous authority over their learning process that most had not experienced prior to this project.

Composition and Functionality

Another interesting component of the design process was the concept of composition and functionality. Composition of the world was discussed in terms of both aesthetic and functional appeal (Gigliotti, 1996). We used the metaphor of dressing a three-dimensional stage when talking to students about this issue (Laurel, 1991). Considerations included where the participant would enter, what they would have in their near and far environment, whether a clear path had been established, or whether the participant was intended to explore at will, and so on. We also presented composition with respect to the learning goals of the environment.

Scenes

One way to design the environment as a whole was to consider different ‘scenes’, similar to the scenes used in a play. These activities might tie to a particular region of the environment, or they may play out in what might be considered a common or multipurpose portion of the environment.

We asked the students to consider setting the scene from both the perspective of the participant and from a holistic view. Students had to consider how to keep the participant engaged in the environment, even if they followed a different route than what was anticipated.

In addition to setting the scene, students had to decide whether the experiences to be had in the environment would be scripted sequentially, or whether there was some flexibility in how a participant might experience the environment. These kinds of decisions were left up to the students, based on what they wanted participants to experience and accomplish in their environment.

Environment Size

We also asked students to consider the size of the environment. Because of the nature of the technology as it stands today, we found that we often have a difficult time controlling such things as ‘flying speed’ when an object is in a participants’ hand. Therefore, it is a more pleasant experience if the world itself is large enough so that all forms of movement can be accommodated (even a very quick mode of flying called turbo-fly), but small enough to avoid having to travel long distances.

Environment size is dictated by object scale. A good rule of thumb in designing objects in a modeling package is 1” = 1’.

Functionality

We found that if an environment is designed so that there are a set of activities that require a number of component parts, it is best to have those component parts relatively close to one and other in the environment. This eases navigational burden on the participant and also allows the programmer a visual check on the items required for the learning that the designers are attempting to facilitate. Of course, there are always those environments that are *intended* to be difficult, such as a treasure hunt world, or a puzzle world, or even some of the adventure games (where tools in the environment are intended to be misleading, or to be used at another point in the adventure). But for the most part, we have found that it is best to put things a) where participants can find them, and b) where net resultant ‘behaviors’ can also be viewed effectively. Students followed these design guidelines when creating their educational environments.

Programming

During the Planning phase, students described environmental interactions in their Behavior Matrix. This document was used to do the actual scripting of the behaviors.

We did the bulk of the scripting at the HIT Lab, since there really was no clear mechanism for allowing students to do the programming themselves. Two of the VRRV team members, Ari Hollander and Howard Rose, wrote a Supercard stack that provided students with a 10 x 10 matrix to determine interactions, and generated the code to implement them. Unfortunately, by the time it was completed Division had upgraded their software, making the Matrix obsolete. Instead, a paper matrix was constructed.

There were certain documents and files that we required the students to provide to us for the culmination of their design process. They include the following:

- Object List & Files
- Behavior Matrix
- World Description
- Final Object/Interaction Master
- Functionality Script, including learning objectives and how these objectives were to be met

After providing all of the above, students were rewarded with a completed environment which they could experience. The most difficult components of the world building process that we experienced were to get students to build a 'base world' upon which all of their objects would reside (if appropriate) and to fill out the Final Object/Interaction Master. An example of this document is presented in Table 10, below.

Table 10 - Final Object/Interaction Master

NAME & DESCRIPTION	**POSITION**	**SCALE**	**FILENAME**	**INTERACTS WITH:**
FREE NITROGEN	X: 0.0 Y: 90.0 Z: 0.0 Pitch: .354 Roll: .000 Yaw: .765	1" = 1'	FREENIT.DXF	PARTICIPANT PICK: CLOUD.DXF RAIN.DXF FIXEDNIT.DXF

Additional Documentation

Students and teachers were also encouraged to provide any additional documentation they thought might help facilitate the process of creating the program files associated with the students' virtual environment. At Kellogg Middle School, we were present for the entire process. However, all available documentation was used to create the final environments.

Depending on the complexity of the environment, the assembly process can generally take from one to several days. In the case of the Kellogg Middle School environments, it took a full 3 days to program the first two environments, water and energy. It took an additional day for each of the other two environments, carbon and nitrogen. Turnaround was very quick.

Experiencing

The environment in which students go through the Experiencing portion of the project can take many forms. Most of the decisions are based on the process selected for this portion-- is there post-testing involved? interviews? survey information to be collected? Are the students allowed to view each other going through their environment or are there constraints placed on the amount of interpersonal interaction that will take place?

At Kellogg Middle School, we worked on the process from both an 'activities' and a 'logistics' perspective. It was just as important to make sure we had enough power for the machines, tables and chairs in which students and evaluators could sit and pencils for survey sheets as it was to ensure that there was at least some opportunity for personal, private exploration.

Another issue was whether to capture students' experience in some way, for example, on video tape, or with a camera. Lighting can become a concern in this case. This might also be an issue if the press has been invited to view students in their environment. Trying to film against glass during daylight hours is difficult at best. At

Kellogg Middle School we did video-tape the students in their constructed environment, but we did so in the corner of the portable farthest from the windows.

During the last two days of the two-week program, students took part in the experiential portion of the 4-step process by experiencing both their own virtual environment, and an environment designed by another student group. The equipment used for the experiential portion of the project was the Division ProVision 100, a proprietary immersive system that includes a substantially enhanced 486 processor, wand, headset, and tracking system for both the participant’s head and hand. An illustration of the Division system is provided in Figure 3, below.

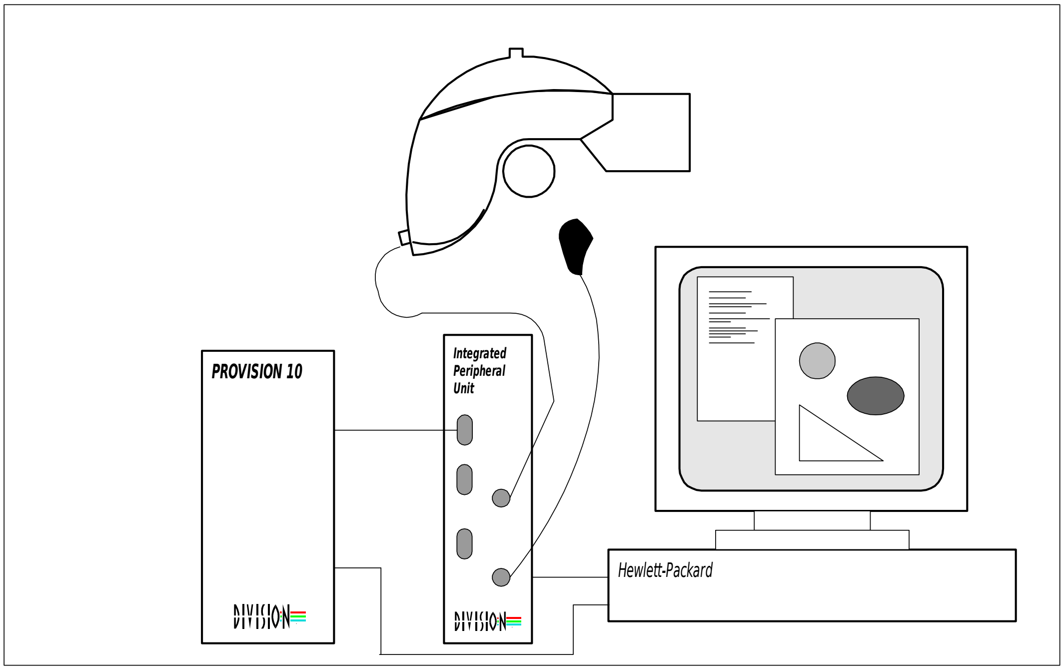


Figure 3 - Division ProVision 100 virtual reality system

The students were prompted by HIT Lab staff to “talk through” their experiences, and to describe what they were seeing, doing and experiencing while in the virtual environment. Occasionally, a student would ask what a particular object was, or what relationship it had to the cycle being experienced. This was especially true when a student was in an environment created by another student group. HIT Lab staff (or another student who was present) would often describe what the object was, or what it could be used for in that particular context. We felt it important to provide the students with as robust an experience as possible, especially as students had limited time (five minutes) in each environment, during which they were challenged to experience all that the environment had to offer.

3.2.3.2. Traditional Instructional Program

During the first 1.5 hour traditional block, subjects were guided by the traditional science teacher in reading wetland-specific portions of the textbook entitled *Life Science: The Challenge of Discovery*. Handouts provided the students with page numbers tied to the cycle being studied, a key word list, and a set of study questions to be answered in class during the discussion session. Students were told that they could seek out additional sources of information should they so desire. It should be noted that most students chose to stay in their classroom and work with the existing text.

During the second, third and fourth 1.5 hour blocks, students were given flowcharts and worksheets to fill out, with specific page numbers relating to the text. Both the flowcharts and worksheets had part of the cycle being studied was already drawn or described. Students were expected to "fill in the blanks."

At the end of the two-week project, some of the students ($n = 41$) got to experience a virtual world that they had studied using traditional learning strategies. The remainder of the students ($n = 25$) experienced a virtual environment in which they had had no instruction.

3.2.3.3. No Instruction Program

The No Instruction Program provided no direct instruction regarding a particular wetland cycle. The teacher who had the control group taught a completely unrelated subject during her time with the students. However, there was a great deal of overlap between the cycles studied and students already knew the water cycle in particular from earlier studies. Some also knew the energy cycle to a degree. Though no direct instruction was provided, it can be assumed that some of the information gleaned during general wetlands study or study of the other cycles may have provided useful information about the no-instruction cycle to the students.

3.3. INSTRUMENTATION AND TESTING

INSTRUMENTS

The instruments used to test the meaning-making process were a hand-drawn concept map and a multiple-choice test designed by the KCOT teachers. These instruments are located in Appendix A, Quantitative Pre- and Post-Test, and Appendix B, Concept Map Pre- and Post-Test. The quantitative test was a 20-question test of all four wetland cycles studied. Questions were broken down as follows:

- 6 Carbon questions
- 5 Energy questions
- 5 Nitrogen questions
- 4 Water questions

The survey was developed by the VRRV team. This instrument was eventually used to test the attitudes and feelings of over 7000 school children who got to experience virtual reality, either through world-building or simply experiencing an environment. This survey is included as Appendix D.

In addition to the above instruments, subjects were observed while in the virtual environment. The subjects were then interviewed immediately after their experience to see what they remembered. These interviews were taped and a paper log was used to capture their recall of objects, interactions, concepts and processes while in the virtual world. An example of the log sheet is included as Appendix E.

TESTING

The multiple-choice pre-test and the concept map pre-test were given to the students in their regular classrooms during the first period of the day on the Friday preceding the beginning of the world-building process. The post-tests were administered on Monday morning the week following the completion of the project.

Video, interview and survey information were collected either during or immediately after their virtual reality experience in both their created world and the world created by another group of students.

3.4. EXPECTED RESULTS

Anticipated results were based on the students' existing knowledge of general wetlands ecology and of each specific cycle, coupled with the way each cycle was studied during the project. It was anticipated that the scores for all wetland cycles would rise regardless of instructional strategy, but that they would rise more for the constructivist approach than the traditional approach. Gains from the traditional approach were expected to be more substantive than those from the no instruction control. Moderate to low gains were expected in the no-instruction approach, because of transfer from other studied cycles.

The conclusions to be drawn from this exploratory study hinged on the development, or construction of meaning from the world building process. By using signs in a variety of formats and through the process of personal experimentation, evidence of abductive reasoning in addition to gains in student content knowledge were expected. The world building process is an intensive undertaking that requires deep understanding of a concept or process coupled with the skills to make that understanding manifest in a manner that can be experienced and enjoyed by others. It was expected this would lead to better post-test performance by subjects in particularly in the world-building group.

In addition, traditional instruction is better than no instruction whatsoever, and better post-test performance by subjects studying cycles using traditional strategies over those who did not directly study a particular cycle were expected.

Regarding the educational value of visiting a virtual world build by other children, moderate gains were expected. The use of this kind of technology has been found to be highly motivating, especially to middle-school age students (Winn, 1995). This project in particular had been presented as a high-stakes endeavor. Students were expected to be very much interested in both the technology in general, and in their personal environments specifically. However, their time 'under the helmet' was very short, so expectations about the value of the virtual environment experience were moderate at best.

The environment in which we housed the technology for the experiential portion of the study was a portable classroom in the back of the middle school. In addition to the short duration of their stay in each environment, the portable was also:

- Noisy (both the Division ProVision machines were loud, as were the twenty children present most of the time who were in the portable being used during the experiential portion of the study, in combination with the ten adults also present)
- Chaotic (we were conducting interviews at the same time subjects were filling out evaluations, and other subjects were 'under the helmet')

Based on these observations, moderate gains based on the virtual experience were expected. These factors can negatively affect learning in any classroom situation, since the potential for distraction was so very high. Though highly motivated, it was feared that students would not be able to concentrate in all the hub-bub.

EDUCATIONAL EMPHASIS

As mentioned above, the KCOT teachers chose to put less emphasis on the water and energy cycles, since these areas had been or would be covered during their standard biology class time. Therefore, educational emphasis was placed on the carbon and nitrogen cycles. For this reason, higher starting (pre-test) scores in both the water and energy cycles and lower pre-test scores for carbon and nitrogen were expected. In addition, greater gains in both carbon and nitrogen scores due to the extra educational emphasis places upon these two subjects were also expected.

HYPOTHESIS AND SCORES

The highest quantitative and qualitative scores were expected to be associated with T1, followed by those associated with T2, then T3. In particular, improvement in concept map representations for the constructivist treatment which included virtual environment design were expected. The design process requires students to think deeply about the interrelationships between objects and interactions in the environment, which has the potential to lead to what is termed “high road” (Salomon, Perkins, & Globerson, 1991) or “deep” (Rose, 1995) transfer. However, we were asking the students to learn content, design skills and educational task analysis skills in conjunction with taking responsibility for a particular role within their group. As we were asking a great deal of the children in a very short time period, this could negatively impact their academic performance.

Regarding the second treatment (T2), children studied the cycle content using the traditional textbook/worksheet approach. Better scores on the traditional concept maps than those presented under the no-instruction treatment were expected, though it was thought that the maps would not be as detailed or complete as those designed during T1. Regarding T3, very moderate gains were expected, but certainly not as substantial as seen in T1 or T2.

VIRTUAL ENVIRONMENT EXPERIENCE

Higher gains in both quantitative and qualitative measures for the virtual environment designed and experienced by the student were expected, in comparison to the experienced environment designed by other students. However, the two “experiences” are clearly interrelated. It was expected that the experience of designing their own world would color the children’s experience of other students’ virtual environments, making it easier to assimilate information from the virtual space due to their design experience. It was assumed that they would try to grasp the same kinds of interrelationships in this environment as well as those designed in their own.

3.5. DATA ANALYSIS

The quantitative data collected via the multiple choice tests were analyzed using ANOVA with groups as a between-subjects factor and pre-post tests as a within-subjects factor. The data collected on the concept maps were rated by two separate raters for completeness, accuracy, and depth of understanding, by using a key-word and concept-flow identification system. The rating process is an extension of a holistic scoring technique developed at the Reading Center at the University of Illinois to assess children's' written compositions. Dr. William Winn and Dr. Patti Char at the University of Washington have piloted an extension of this technique to evaluate pictorial representations, such as those found in concept maps. A first pass was made through the data to seek out representative "anchors"; the best and worst representations that the raters agree upon. A second pass was made through the data during which each rater evaluated representations or descriptions holistically based on the anchors. Differences of opinion as to the value of a particular item were negotiated on a case-by-case basis. The same technique was used to analyze the performance log.

The multiple choice test provided a measure of declarative knowledge and the concept maps a measure of interrelational knowledge. The interview sheets provided perspective on the children's procedural knowledge regarding the subject area as they described in narrative form their personal interaction with the information presented in the virtual environment.

The survey data was a 15-question Likert Scale and essay question document that was administered to the students after their interview was complete. Students were asked to judge their perceptions of their enjoyment of the process and experience, the educational value of the process and their experience and whether they would choose to undertake such an activity again.

CHAPTER 4: FINDINGS

4.1. OVERVIEW

Statistical analysis was conducted on all of the measures collected: objective pre- and post-tests scores, concept map pre- and post-test scores for both the world that they built and a chosen world that they wished to represent, interview data for all students who experienced VR and survey information. ANOVA tables relating to these results can be found in Appendix F: ANOVA Tables.

4.1.1. OBJECTIVE TESTS

Regarding the objective tests, an ANOVA with test occurrences as a within-subjects factor of pre- ($M = 8.87$) and post-test ($M = 12.35$) scores revealed a significant improvement in scores overall, $F(1, 79) = 97.58$, $p < .001$. There was no significant main effect based on the world (T1) that the students built, $F(3, 79) = 1.78$, $p > .05$, and no interaction effects. These results are illustrated in Table 18.

It was unclear whether instructional paradigm alone had an effect on the children's understanding of particular cycles based on these findings. However, treatment effects were found for Concept Map data.

4.1.2. CONCEPT MAP ANALYSIS

The Concept Maps provided the richest data from all of the measures taken. Rated using holistic scoring techniques, found in Appendix C, Concept Map Scoring Criteria, each cycle described was carefully examined to determine if the student had provided information in a manner fitting the criteria. Raters were blind to treatment. Scores for concept maps ranged from 0 - 4. Interrator reliability for concept map analysis, using the Wilcoxon Matched Pairs test was significant ($Z = -3.5279$; $p < .001$).

Sixty-seven subjects drew four maps: two “built” (before and after the world they built and experienced (T1)), and two “chosen”, i.e. a self-selected representation of one of the three other cycles being studied (before and after the treatment had been administered (either T2 or T3)). Not surprisingly, many of the children selected water as the cycle to represent for their “chosen” drawing; the cycle best known to them prior to their experience in this project. Mean scores by group by pre- and post-test for both built and chosen maps is presented in Table 11, below.

Table 11 - Concept Map Means for Pre- and
Post-tests, and Built vs. Chosen Environments

Mean Scores Built vs. Chosen by Group	Pre-test		Post-test	
	Built	Chosen	Built	Chosen
Carbon (*n* = 14)	1.57(1.45)	.93(1.14)	2.57(1.40)	2.64(1.22)
Energy (*n* = 17)	1.00(0.50)	2.53(1.46)	2.71(0.92)	2.71(1.40)
Nitrogen (*n* = 14)	.93(0.47)	3.00(1.53)	2.86(0.95)	3.71(1.50)
Water (*n* = 23)	2.26(1.18)	1.48(1.08)	3.30(0.70)	2.22(1.28)
Grand Means (*n* = 68)	1.53(1.14)	1.93(1.48)	2.91(1.00)	2.60(1.35)

Note: Standard deviations in parentheses.

Concept Maps were analyzed by ANOVA in two ways. The first analysis consisted of two within-subjects factors, pre- and post-test measures, and built vs. chosen measures. Group was used as a between-subjects factor. A second analysis was conducted on instructional treatment (Constructivist, Traditional, and No Instruction), as a within-subjects factor for Constructivist vs. Traditional, and Constructivist vs. No Instruction, and as a between-subjects factor for Traditional vs. No Instruction.

The first analysis, a within-subjects ANOVA comparing pre- and post-test scores, by built vs. chosen world yielded no main effect based on the world that the children drew, $F(3, 63) = 1.02$, $p > .05$. These results are illustrated in Table 19. However, there was a significant pre-post effect, $F(1, 63) = 71.75$, ($p < .001$) and no interaction effects $F(3, 63) = .71$, ($p > .05$). These results are illustrated in Table 20.

This pre-post effect is consistent for all concept map measures. It is clear that the students' cognitive gains in procedural and relational knowledge improved. What is also clear is that the wetlands project resulted in significant comprehension and understanding of the subject matter, regardless of group.

Further concept map analysis indicates no significant main built effect, $F(1, 63) = 2.04$, $p > .05$, and a significant interaction effect between built vs. chosen and group, $F(3, 63) = 15.56$, $p < .001$. These results are presented in Table 21. Further analysis yeilded a significant interaction $F(1, 63) = 10.47$, ($p < .005$) between pre-post and built-chosen, and a significant interaction effect $F(3, 63) = 6.10$, ($p < .01$) between pre-post, built-chosen and group. These results are presented in Table 22.

These findings indicate that not only were the pre- and post-test scores significantly different, but the scores varied based on whether the children had built the world the represented in their drawings, or whether it was the world that they had chosen to represent. Furthermore, the additional interaction between group, pre-post and built-chosen indicates that the group the children were in also had a significant effect on this interaction.

As can be seen in Figure 4, below, the Carbon group experienced the most significant gains in *both* built and chosen worlds. In all other groups, pre-post differences were much more substantial for the world that they built, rather than the world that they chose to represent. It is interesting to note that the Carbon group contained the three intellectually challenged children in the KCOT program. In previous (Osberg, 1993b) and subsequent (Winn, 1997) research, it has been found that virtual environment design tends to help learning impaired children even more substantially than non-learning impaired students. These findings could be indicative of this trend.

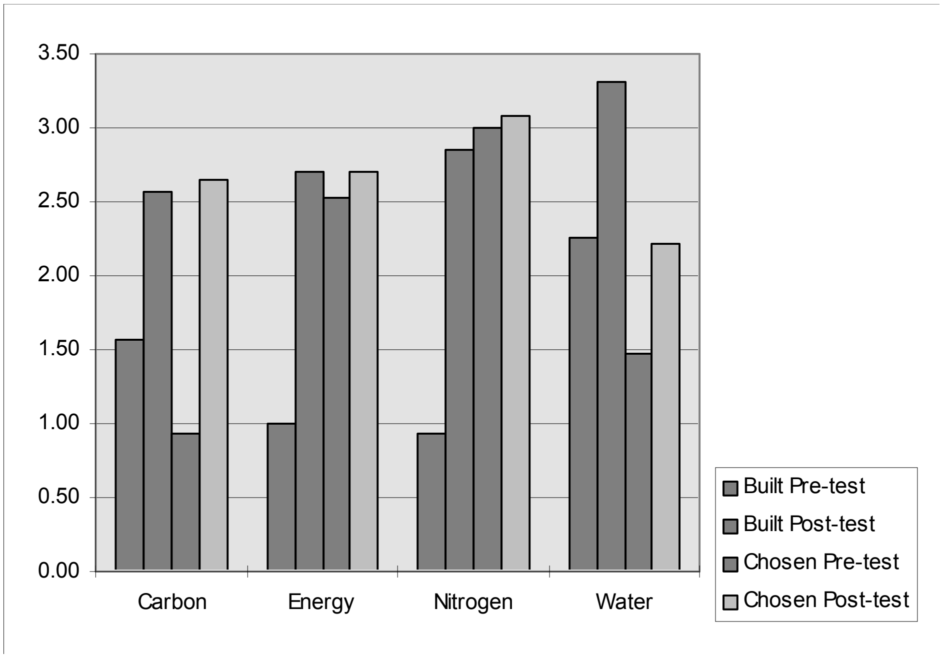


Figure 4 - Concept Map Pre- and Post-test Built vs. Chosen cycles by Group

What can be seen in comparing group information is that there are gains for all groups in all instances, and for three of the four groups, gains are much less substantive for the chosen concept map representations. This is what had been anticipated based on the assumption that most subjects, given their choice, would draw a cycle known to them, namely water. However, for the Carbon group, the gains for chosen world representations were even more substantive than for their built environment. This inconsistency may be attributable to the less robust knowledge base of some of the Carbon group members.

Built world concept map gains were consistent for all groups, resulting in at least a +1.0 rise in scores on a 4-point scale.

Another interesting way to look at this same data set is to alter the graphics to show the built vs. chosen scores for each group. An illustration of this analysis is presented in Figure 5, below.

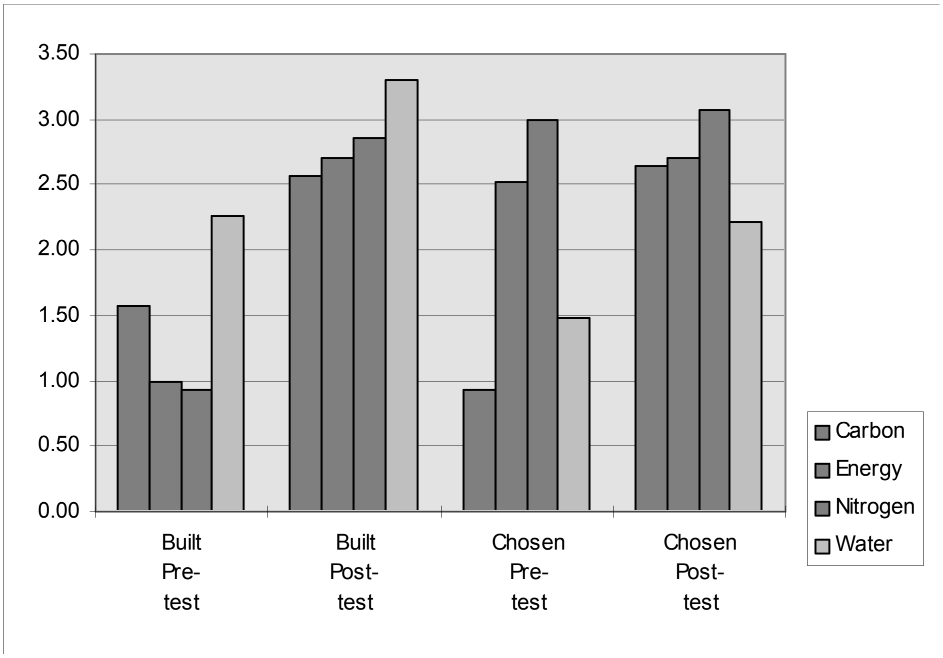


Figure 5 - Concept Map Pre- and Post-test scores
by Group by Built vs. Chosen cycle

What can be seen from this graph is that for both built and chosen concept map representations for all groups, the post-test scores are consistently higher than pre-test scores, and that the Water group did the best on the pre-test, again because this cycle was already known.

Treatment comparisons yielded the most interesting results of all of the analyses conducted. In comparing concept map scores based on treatment (Constructivist, Traditional and No Instruction), within-subjects ANOVAs were conducted to compare Constructivist vs. Traditional scores, and Constructivist vs. No Instruction scores, and a between-subjects ANOVA comparing Traditional vs. No Instruction scores.

To illustrate the comparisons more fully, a means table is presented below which will be referenced throughout this section. In Table 12, means for each treatment group for both built and chosen cycle representations, and pre- and post-test scores are presented.

Table 12 - Concept Map Means for Pre- and
Post-tests by Treatment

Mean Scores for Pre- and Post-tests by Treatment	Constructivist	Treatment Traditional	No Instruction
Constructivist vs. Traditional (*n* = 43)			
Pre-test	1.67(1.27)	1.74(1.56)	
Post-test	2.79(1.04)	2.67(1.34)	
Constructivist vs. No Instruction (*n* = 24)			
Pre-test	1.28(0.84)		2.25(1.29)
Post-test	3.12(0.93)		2.46(1.38)
Traditional (*n* = 43) vs. No Instruction (*n* = 24)			
Pre-test		1.74(1.56)	2.25(1.29)
Post-test		2.67(1.34)	2.46(1.38)

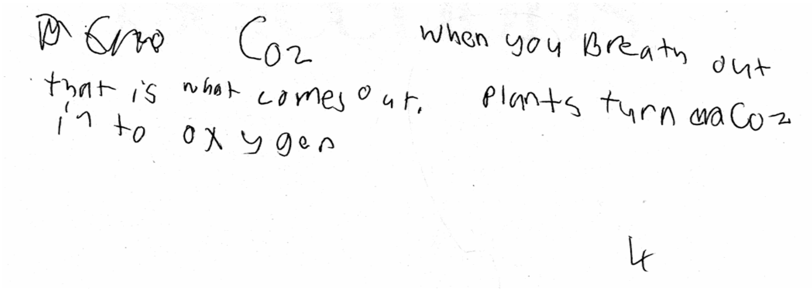
Note: Standard deviations in parentheses.

4.1.2.1. Constructivist vs. Traditional Treatment Analysis

For the Constructivist vs. Traditional comparison (*n* = 43), using a within-subjects ANOVA, a significant $F(1, 42) = 58.23$, ($p < .001$) pre-post effect was found. These results are presented in Table 23. Further analysis yeilded no significant effect for the cycle illustrated under either instructional paradigm $F(1, 42) = .01$, ($p > .05$), as shown in Table 24, and no interaction effects, $F(1, 42) = .41$, ($p > .05$), as shown in Table 25.

This finding indicates that instructional paradigm did not significantly affect the children's ability to represent a wetlands cycle. Both the Constructivist and Traditional learning paradigms resulted in significant gains. Though the means in each case varied, as can be seen in Table 10, above, they did not differ significantly, which refutes my original hypothesis that the Constructivist learning paradigm would provide more substantive results than Traditional education, at least using the assessment criterion that we established.

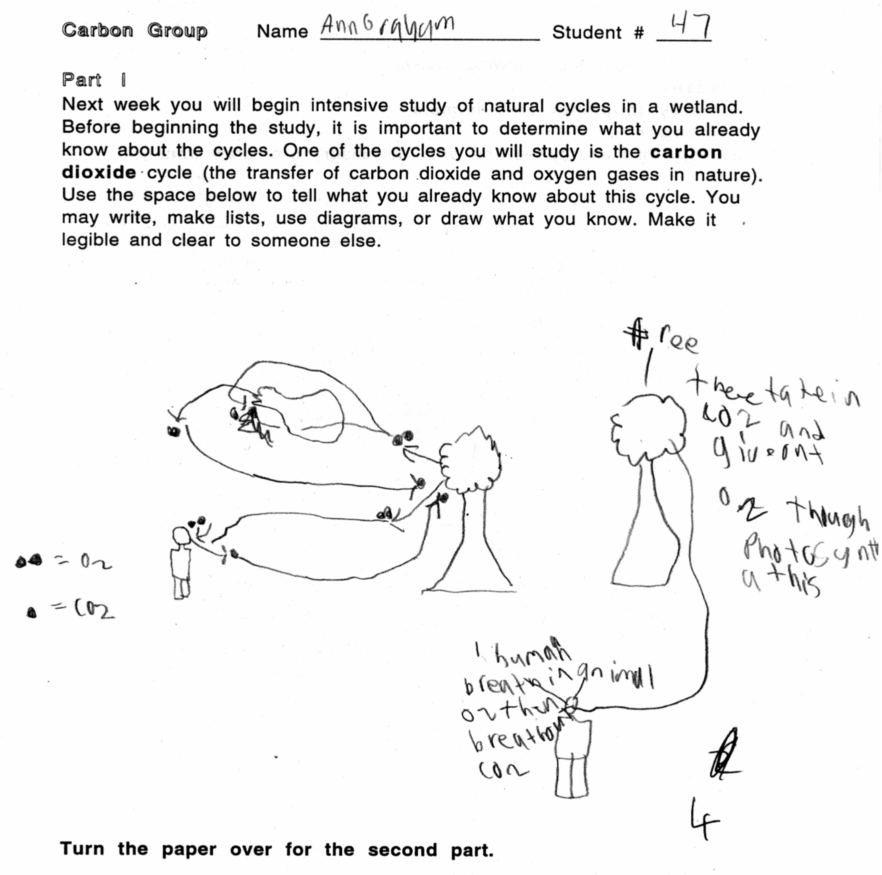
However, using the actual drawings in (Ann Graham, Carbon) Figures 6 and 7 as a comparison, there are other conclusions that can be drawn. In this example, the concept maps illustrated under both the Constructivist and the Traditional treatment are visually richer, more complex and to a degree more accurate after the virtual world building experience than that created during the pre-test. This comparison is consistent in reviewing the subjects' concept maps, regardless of group or treatment. Both are technically correct, yet there is additional value in the creative representation of information, especially in the transformation or translation of information from one symbol system to another. This transformation process is one means to assess the development of students visual literacy (Mones-Hattal & Mandes, 1995; Kirby, Moore & Schofield, 1988), which is defined by Farmer (1987) as "the abilities to read and interpret visually and to express oneself honestly and accurately by translating visual symbols into verbal language and vice versa".



Co_2 when you Breatn out that is what comes out. Plants turn Co_2 i'n to oxygen

4

Pre-test Representation



Carbon Group Name AnnGraham Student # 47

Part I

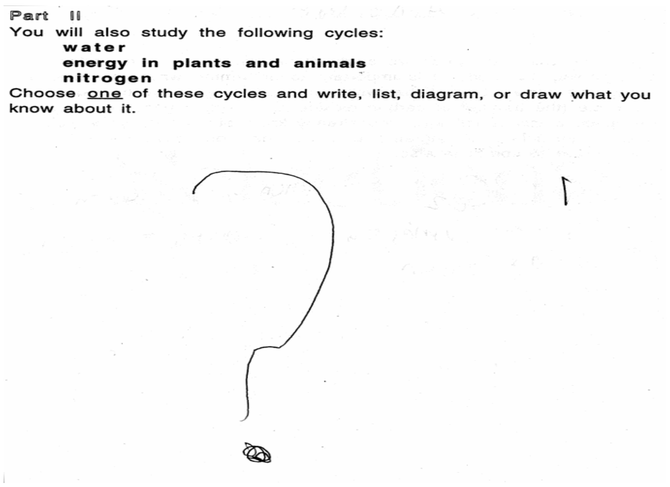
Next week you will begin intensive study of natural cycles in a wetland. Before beginning the study, it is important to determine what you already know about the cycles. One of the cycles you will study is the **carbon dioxide** cycle (the transfer of carbon dioxide and oxygen gases in nature). Use the space below to tell what you already know about this cycle. You may write, make lists, use diagrams, or draw what you know. Make it legible and clear to someone else.

4

Turn the paper over for the second part.

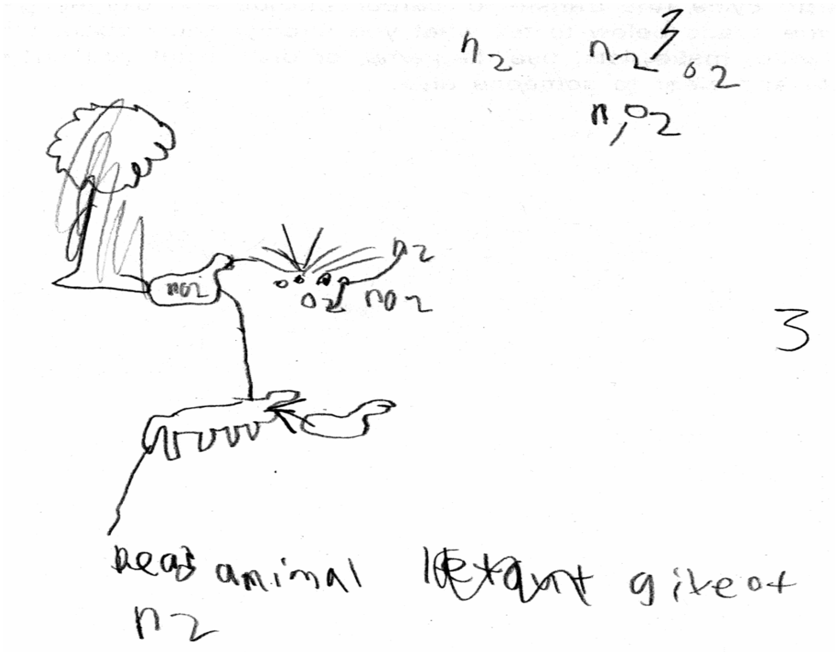
Post-test Representation

Figure 6 - Constructivist Treatment Pre- and Post-test Concept Map comparison



Part II
You will also study the following cycles:
water
energy in plants and animals
nitrogen
Choose <u>one</u> of these cycles and write, list, diagram, or draw what you know about it.

Pre-test Representation



Post-test Representation

Figure 7 - Traditional Treatment Pre- and Post-test Concept Map comparison

In this study, almost all source information regarding wetlands ecology was primarily text based, with the addition of limited videodisk, CD-ROM or Internet-based images and sounds. The translation process was embodied in the subjects' ability to transform this text-based source information into an interactive, visual representation by creating a virtual environment. The comparison between the pre and post-test representations is clear; the effects of translating that information into a visual representation provides an additional element to the students knowledge base above and beyond technical accuracy.

This richness could be described, in Gibsonian (1986) terms, as arising from the "cognitive process that includes mental rehearsal, introspection, and visualization, and distinguishes itself as a thought process different from verbal thinking whereby each exposure to the visual image permits the observer to become a keener interpreter of the visual display, i.e. to see more and more element within the display over time".

This expanded perspective may be the result of the constructivist learning experience reified in world design. Students used the signs they created to experiment with interactions, leading to deeper understanding of the meaning behind the signs. Cunningham's (1992) abductive reasoning model was used during the design process, but was particularly applicable during the experiential portion of the project. Children, through the development of hypotheses and the process of experimentation developed an understanding of the salient characteristics and components used in each cycle. This visual, experiential understanding allowed students to utilize the visual component in addition to the textual description to clarify and elucidate the carbon cycle in their concept map post-tests. This process was consistent for all groups.

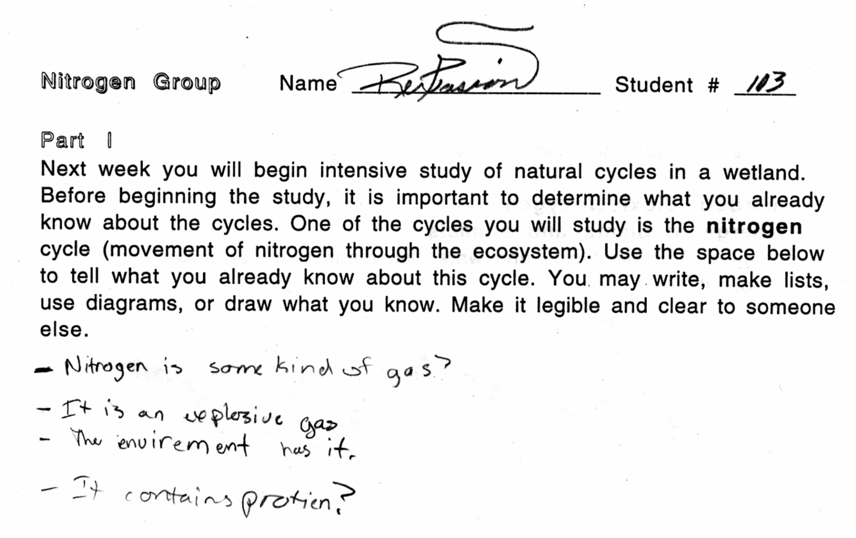
These post-test concept map representations relate also to Morris & Hampson's (1983) image taxonomy in that what this student has chosen to represent has become "real" for her, even though the representations may not be directly analogous to the natural world. In other words, when she thinks about these cycles, it is in this form. It also relates to Mones-Hattal & Mandes (1996) perception that virtual reality involves visual thinking, which deeply affects our perceptions, and our memory.

4.1.2.2. Constructivist vs. No Instruction Treatment Analysis

For the Constructivist vs. No Instruction treatment comparison, a significant pre-post effect was found, $F(1, 23) = 18.40$, ($p < .001$). These results are presented in Table 26. Further analysis yeilded no significant built-chosen treatment effect, $F(1, 23) = .45$, ($p > .05$), as presented in Table 27, and a significant pre-post, built-chosen treatment interaction, $F(1, 23) = 18.25$, ($p < .001$), as presented in Table 28.

In conducting paired t-tests to analyze mean scores for pre-post/built-chosen worlds, the pre- and post-test means for the Constructivist treatment were significant ($p < .001$), but the No Instruction treatment means did not vary significantly.

This finding indicates that concept maps improved significantly for worlds that the children built themselves, but not for worlds that were drawn by choice in which children had received no instruction. This supports a portion of my original hypothesis that constructivist learning is certainly more valuable than no instruction whatsoever. Even so, the children's representations were much more pictorial after the world building experience, as was true for the comparison between Constructivist and Traditional treatments (Isaac Ralston, Nitrogen), as illustrated in Figures 8 and 9, below.



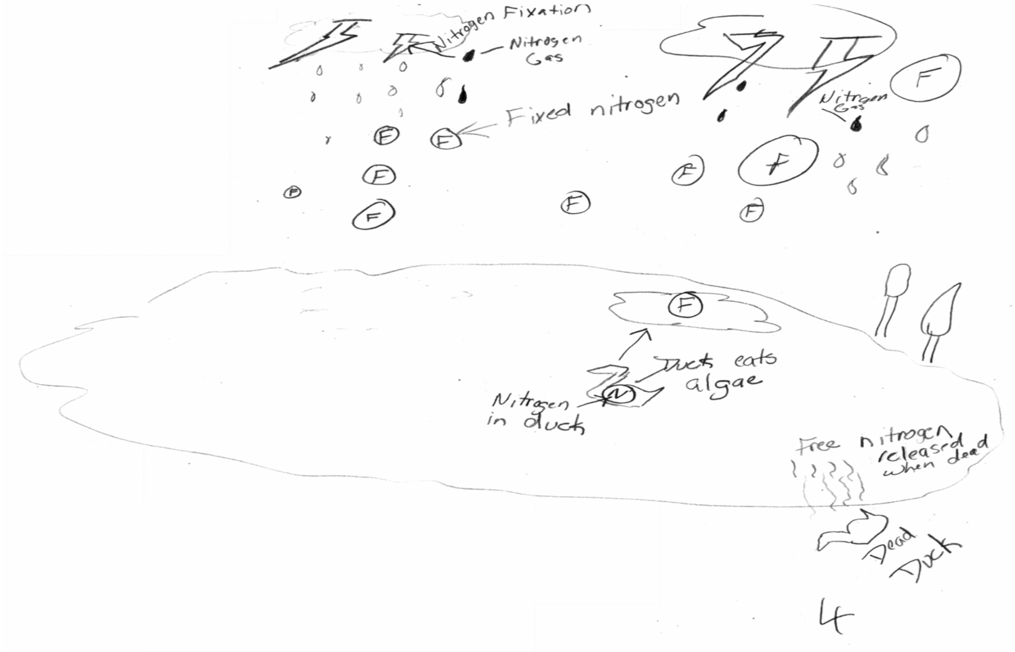
Nitrogen Group Name ________ Student # 103

Part I

Next week you will begin intensive study of natural cycles in a wetland. Before beginning the study, it is important to determine what you already know about the cycles. One of the cycles you will study is the **nitrogen** cycle (movement of nitrogen through the ecosystem). Use the space below to tell what you already know about this cycle. You may write, make lists, use diagrams, or draw what you know. Make it legible and clear to someone else.

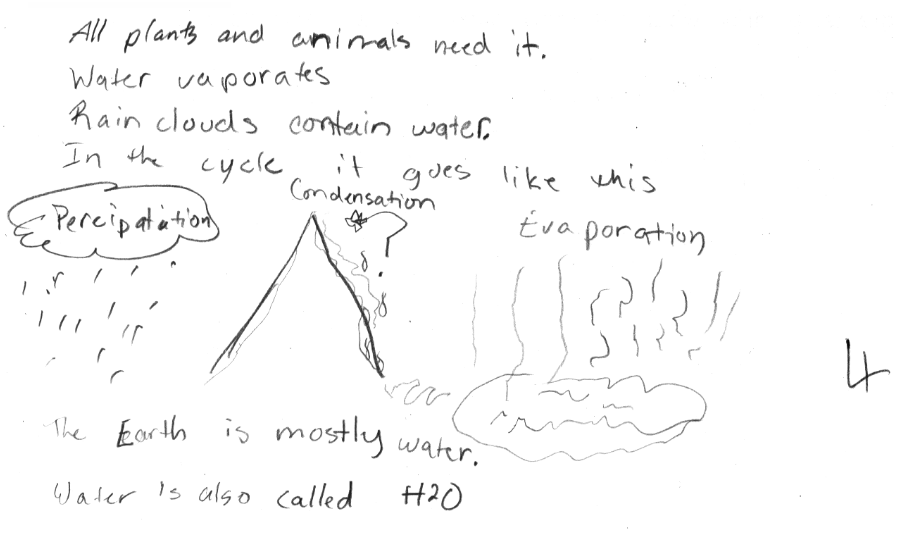
- Nitrogen is some kind of gas?
- It is an ueplosive gas
- The envirement has it.
- It contains protien?

Pre-test Representation

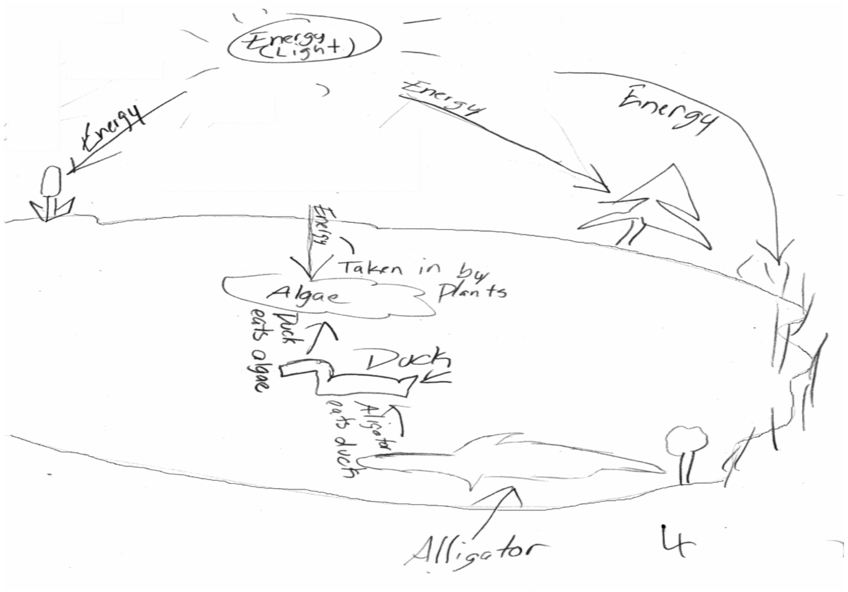


Post-test Representation

Figure 8 - Constructivist Treatment Pre- and Post-test Concept Map comparison



Pre-test Representation



Post-test Representation

Figure 9 - No Instruction Pre- and Post-test
Concept Map comparison

4.1.2.3. Traditional vs. No Instruction Treatment Analysis

For the Traditional vs. No Instruction comparison, both a within-subjects analysis for pre-post measures, and a between-subjects analysis comparing the individuals in the Traditional vs. the individuals in the No Instruction treatment group were conducted. In doing so, no significant score differences were found between the two treatments, Traditional vs. No Instruction, $F(1, 65) = .06$, $p > .05$, as presented in Table 30. Further analysis yeilded a significant pre-post effect, $F(1, 65) = 5.35$, $p < .05$ and a significant pre-post, treatment interaction effect, $F(1, 65) = 4.00$, $p = .05$, as presented in Table 31.

In conducting paired t-tests to analyze mean scores for pre-post/treatment interaction, the difference between Traditional pre- and post-scores was significant ($p < .001$), but the No Instruction pre- and post-test scores did not vary significantly.

This implies that though Traditional education provided the students opportunity to improve their knowledge on that particular wetland cycle, the No Instruction treatment does not does not. The interaction effect must be attributed to the differences in instructional treatment.

4.1.2.4. Summary of Treatment Analyses

Based on the findings above, both the Constructivist and Traditional educational approach were both educationally valuable in that pre- and post-test scores for both treatments improved significantly. Further analysis indicated that the Constructivist approach is more educationally valuable than No Instruction, but that the comparison between the Traditional and No Instruction treatments did not yield significant differences between the two treatments. However, pre- and post-test scores were significantly different for the Traditional approach, indicating educational improvement, but not for the No Instruction treatment.

These analyses were based on subjects' built vs. chosen cycle representations. Given that the students chose to represent was most often water, regardless of whether the treatment for that cycle was Traditional or No Instruction, it is not surprising to see no significant treatment difference between Traditional and No Instruction.

What was surprising was to see no significant treatment difference between Constructivist and Traditional treatments. In the end, it becomes a matter of interpretation, and of desired outcomes. If we choose to foster and value creativity and alternative forms of knowledge representation in our educational settings, such as was illustrated in the concept map comparison in section 4.1.2.1 and 4.1.2.2, then the Constructivist approach is one way to facilitate such knowledge acquisition and application. If instead we choose to focus on the 'technically correct' version of knowledge recall and application, without giving additional thought to the inventiveness or cognitive value in translating that information, both the Constructivist and Traditional approaches are equally educationally valuable.

4.1.3. INTERVIEW ANALYSIS

The interviews were conducted just after the students had completed their virtual experiences, both within the world that they built, and the world that they visited that had been constructed by another student group. Interviewers asked students to recall the cycle just experienced, as represented in the virtual environment.

Many of the students, in addition to using words to describe their experiences, moved their bodies in the same way that they had while in the virtual environment. This indicates a somatic memory that is not described in the text-based data, but is well worth mentioning (Kraft & Sakofs, 1989).

Interviews were rated on a scale of 0-5 using a similar set of criteria as used to rate the concept maps. The information gathered during these interviews was intended to test whether the students remembered the steps to each respective cycle, as well as the key components required to complete each cycle. The evaluator also kept track of how often the student needed to be prompted, whether steps were remembered in order or whether the remembrances were somewhat scattered, and other comments that the students had about their experiences. The interviews were also video-taped for review purposes. Rating criteria are described in Table 13, below.

Table 13 - Rating Criteria for Interview Logs

CARBON CYCLE

1. Cycle must be described explicitly.
2. The steps in the process need to be explained.
3. Steps in the Carbon Cycle to be identified: CO_2 formation, O_2 formation, decomposition.
4. Objects needed to complete the cycle: Plants giving off O_2 and taking in CO_2; animals giving off CO_2 and taking in O_2. Release of carbon from the system through decomposing flesh or feces.

ENERGY CYCLE

1. Cycle must be described explicitly.
2. The steps in the process need to be explained.
3. Steps in the Energy Cycle to be identified: The Food Chain, and how energy transfers from one organism to another, including decomposition and its contribution to plant growth and regeneration.
4. Objects needed to complete the cycle: Blue-green algae, fish, dragon flies, turtle, duck, fox, alligator, birds.

NITROGEN CYCLE

1. Cycle must be described explicitly.
2. The steps in the process need to be explained.
3. Steps in the Nitrogen Cycle to be identified: Nitrogen fixing, movement of nitrogen through the food chain, denitrofication, decomposition (release of fixed and free nitrogen into the air and soil).
4. Objects needed to complete the cycle: Free nitrogen, lightening storm (cloud with lightening emitting from it), rain transferring fixed nitrogen into the ground for absorption into plants, nitrogen fixing bacteria, plants with fixed nitrogen, duck (to eat plants), fox (to eat duck), dead duck and feces, denitrifying bacteria.

WATER CYCLE

1. Cycle must be described explicitly.
2. The steps in the process need to be explained.
3. Steps in the Water Cycle to be identified: cloud formation (condensation), rainfall (precipitation), groundwater accumulation, water vapor (evaporation).
4. Objects needed to complete the cycle: Energy from the sun, water vapor, clouds, rainfall, lake representing groundwater accumulation.

The interview data, analyzed using within-subjects ANOVA, indicate a significant main effect $F(3, 65) = 2.79$, ($p < .05$) based on the world that the subjects built, as presented in Table 33. This indicates that children's ability to accurately describe their experiences, regardless of whether the world was the one that they themselves built, or was built by another student group depended at least partially on the group in which they were in.

There was also a significant *F*(1, 65) = 14.68, (*p* < .001) built-experienced main effect, and a significant interaction effect, *F*(3, 65) = 4.37, (*p* < .01) between built vs. experienced and group, as presented in Table 34.

In analyzing the mean scores for each group, the differences based on group illustrated in Table 14, below, appear to be dictated by low Carbon Interview scores for their experienced (not built) world. The three learning impaired students in the KCOT program had all been placed in the Carbon group, the group that experienced Nitrogen world (the most difficult cycle to understand). All of the other groups experienced the three easier worlds, carbon, energy and water, which is at least a part of the reason that they were able to accurately recount and describe their experienced cycles.

Table 14 - Mean Scores for Interview Data by Group

Mean Scores Group	Built	Experienced	Exp. World
Total Sample (*n* = 69)	4.06(1.07)	3.57(1.31)	
Carbon (*n* = 18)	3.94(1.16)	2.78(1.48)	Nitrogen(**T;18**)
Energy (*n* = 19)	4.26(1.28)	4.37(.895)	Water(**N;4**)/Nitro(**T;15**)
Nitrogen (*n* = 19)	4.00(.882)	3.53(1.31)	Energy(**N;8**)/Carbon(**T;11**)
Water (*n* = 13)	4.00(.913)	3.54(1.05)	Energy(**N;13**)

Note: Standard deviations in parentheses. Treatments: T=Traditional, N+ No Instruction. Number of subjects per treatment follows semicolon.

In fact, the group with the highest mean Interview scores for both built and experienced environments was the Energy group, who had contact with what the teachers felt were the two easiest cycles, energy and water. The Nitrogen and Water groups were both very close in scores for both built and experienced environments.

4.1.4. SURVEY ANALYSIS

The survey was analyzed using frequency distributions. The survey itself can be found in Appendix D.

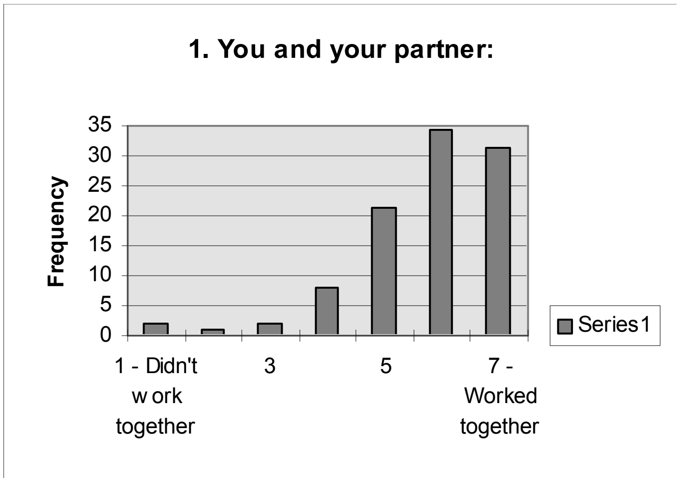
Questions were asked about both the process of developing the virtual environment, and about the experience of being in the virtual space to ascertain which portion(s) of the project subjects deemed to be most valuable or enjoyable, and whether they would consider undertaking such a project in their educational environments in the future.

Results indicate that the students very much enjoyed the "Virtual Wetlands", as we billed the project. They liked both building and visiting their environments, and wanted to incorporate the use of virtual technology into the curriculum for students who would be studying this subject in the future. Almost all of the students wanted to experience virtual reality again.

Using the combination of a 7-point Likert scale and two essay questions at the end of the survey, we found that often students tended to polarize towards either the top or bottom of the scale, with very few questions having a normal distribution. The fourteen questions on the survey are described below by the kind of issue addressed by the question; Process, Learning and Teaching, Task Understanding and Difficulty, Perceived Value and Overall Enjoyment, Physical Discomfort, and Presence. An Essay Question analysis follows.

4.1.4.1. Process Analysis

Regarding the building process, we first asked how each individual had faired with their partner, and their group. Frequency distributions for each of these questions is provided in Figure 10, below.



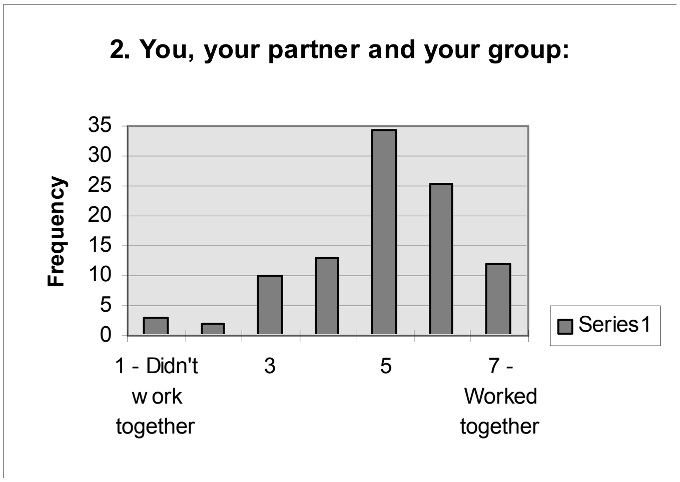


Figure 10 - Frequency data regarding pair and group participation

When asked whether they had worked together as partners during the project, 87% of the respondents answered from 5 - 7, indicating that they and their partner(s) worked together, rather than working individually. When asked if they interacted with others in their group, 72% of the respondents answered from 5 - 7, suggesting that they interacted often or frequently with their other group members. This indicates that the study facilitated collaborative learning, both in pairs and in the larger group context. This is one of the foundations of the constructivist paradigm; to mentor and support each others' learning processes.

4.1.4.2. Learning and Teaching Analysis

The third and fourth questions on the survey had to do with learning and teaching to discover what students thought the end goal of the project was; to learn themselves, or to develop a system whereby others could learn what they learned, which implies that they have first learned the material themselves.

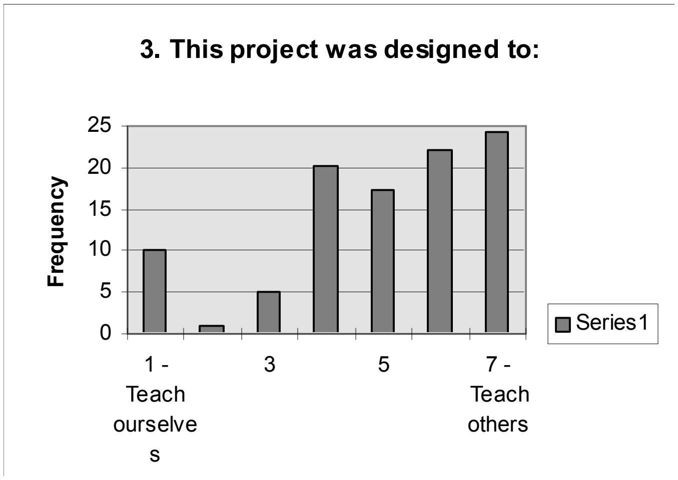


Figure 11 - Frequency distributions regarding learning and teaching perceptions

The students were asked what the purpose of the project was; to teach themselves, or to teach other students. Figure 11, above, illustrates that 63.6% of the respondents answered between 5 - 7, indicating that the project was designed to provide them an opportunity to develop and environment to be used to teach other students. This was the way that the design process was introduced to the students, though it implies that they too are learning the material prior to sharing it with others. 10% of the students responded with a 1, indicating that the project was designed solely to teach the wetland cycles to themselves. Slightly over 20% of the students responded with a 4, indicating that both cases were true.

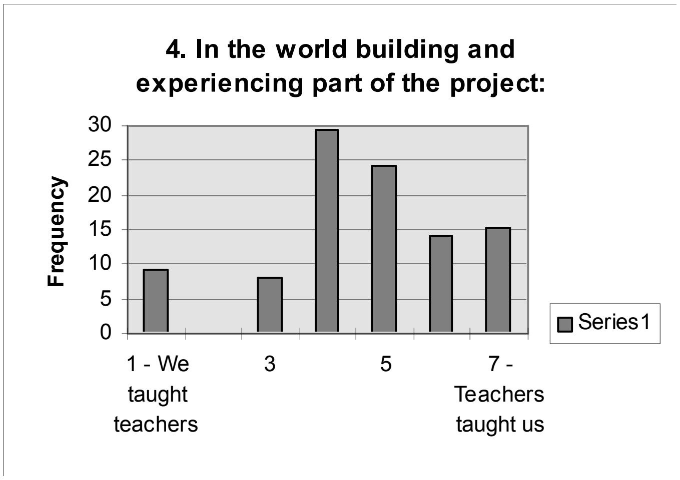


Figure 12 - Frequency distribution regarding teaching locus of control

Figure 12, above, illustrates the students' response to their perceptions on who was doing the teaching; whether they themselves were in a position to 'teach the teachers', or whether the teachers continued to 'teach them'. This question was poorly worded, especially since the bulk of the learning that took place in the context of world-building was under the Constructivist treatment, where all the learning in the classroom was self-directed. Nonetheless, a substantial (54%) portion of the students answered either 5, 6, or 7, at the top end of the scale indicating that the 'teachers continued to teach us'. This response is a bit baffling. Perhaps the students' assumed that the Traditional treatment was representative of teacher presence and control, which did continue throughout the course of the project, or that they thought of HITL representatives as 'teachers'.

4.1.4.3. Task Understanding and Difficulty Analysis

The questions regarding task understanding and ability to complete the task were designed to develop an understanding about how much the students understood what they were to accomplish while in the virtual environment, as well as how well they were able to accomplish it. Being in a virtual space, especially for a novice, can be quite challenging. In the wetlands environments, students could rise and sink to any elevation they desired by ‘flying vertically’. This is not always the case; movement can be constrained to a certain plane or level, but in our four environments, students could fly to any altitude they chose. Therefore, their normal mode of locomotion (walking) was temporarily supplanted by the sensation of ‘flying’. This can be very disconcerting for some individuals, especially for adults. Children seem to be more adaptable to alternative forms of perceptual ‘movement’.

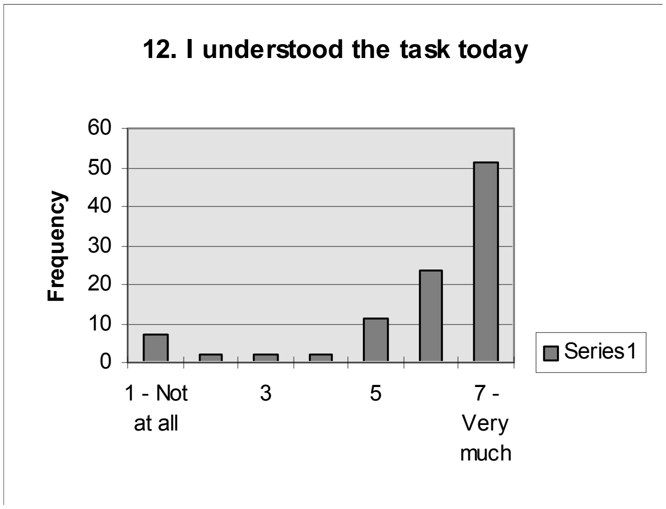


Figure 13 - Frequency distribution regarding task understanding

The frequency distribution for the first question, regarding understanding of the task (which was to interactively complete the cycle portrayed in the environment), is illustrated in Figure 13, above. 86.5% of the students answered at the high (5 -7) end of the scale, indicating that they understood the task at hand. The remaining 13.5%, who answered between 1 - 4, were not as well informed about the task going into the virtual environment.

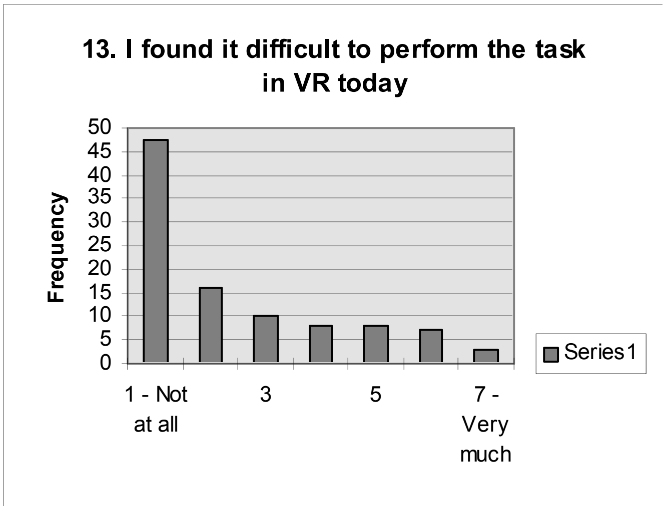


Figure 14 - Frequency distribution regarding task difficulty

When asked about the difficulty of completing the task, as illustrated in Figure 14, above, 73.7% of the students answered between 1 - 3, indicating relatively little difficulty in completing the task. However, the remaining 26.3% answered between 4 - 7, indicating moderate to severe difficulty in completing the task.

What these figures indicate is the need for greater opportunity to acclimatize to the virtual environment. Had there been more time, a 'training round' in another virtual space would have been advantageous, which was a practice we incorporated later into the project. Kellogg Middle School, as the pilot program, suffered in this regard. Children were perhaps not as well prepared for the navigational and interactive components of a virtual space as they could have been with a practice round under their belts.

4.1.4.4. Perceived Value and Overall Enjoyment Analysis

Two questions had to do with the students' perceived value of virtual reality as a learning tool, and one with the overall enjoyment factor of the project as a whole.

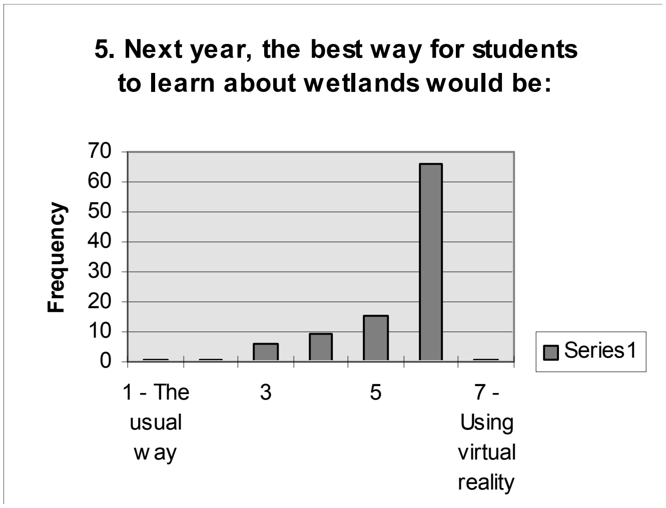


Figure 15 - Frequency distribution regarding next year's students wetlands curriculum

In asking the students' how they best thought their cycle could be conveyed to next year's 7th graders, whether through the means generally available to them in the constructivist classroom, or whether to incorporate virtual reality into the learning experience, 92% of the respondents answered between 5 - 7, indicating they would rather incorporate a virtual reality component into the learning process. These data are illustrated in Figure 15, above.

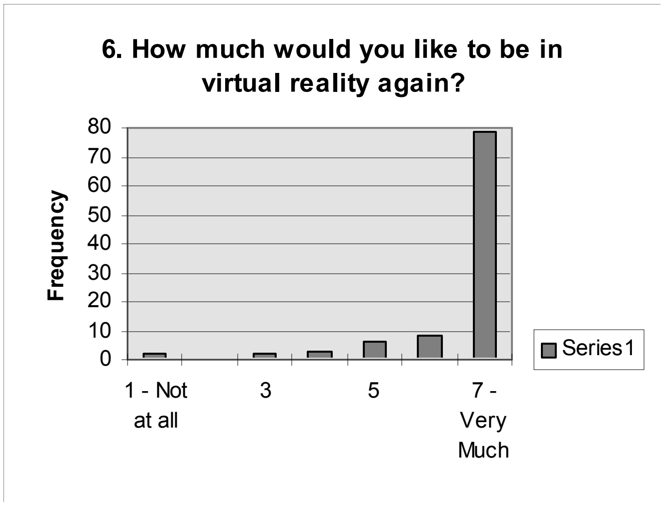


Figure 16 - Frequency distribution regarding
desire for another virtual reality experience

When asked if they would like to visit a virtual environment again, as illustrated in Figure 16, above, 92% again answered 5, 6 or a very resounding 7, indicating strong interest in such an endeavor.

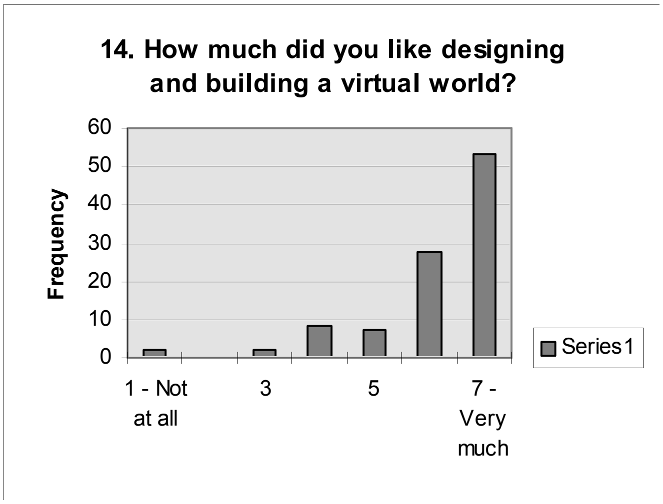


Figure 17 - Frequency distribution regarding
enjoyment of the design/build process

In Figure 17, above, the frequency distribution for the question regarding enjoyment in designing and building the virtual environment is illustrated. 87.8% of the respondents answered between 5 - 7, indicating that they enjoyed the process, 53% of which enjoyed the process very much. Those that answered between 1 - 3 comprised 4% of the respondents. The remaining 8.2% answered 4, indicating a neutral position on their enjoyment level.

In discussions with students during and after the project, almost everyone wanted to use the technology and the process for their very next project in class, as well as for a special district-wide science competition. In fact, we left the modeling software on the computers at Kellogg, and at all other environments in which we engaged in a world-building process for this very purpose. Unfortunately, we were not in a position to provide the display technology as well, an issue addressed further in the discussion section.

It was very satisfying to see such positive values with regard to both the design/build and experiential portions of the project. Clearly, this was a project that was perceived by the students to be of value, and one that they enjoyed as well.

4.1.4.5. Physical Discomfort Analysis

Two questions were asked about potentially negative physical feelings that the students might have experienced while in the virtual space; one on nausea and one on dizziness. It is a well known fact that for a small percentage of the population, being in a virtual environment can cause vertigo, headaches, and nausea. (Prothero, et al., 1995). It was interesting to see how many individuals experienced these negative physical feelings in this particular project.

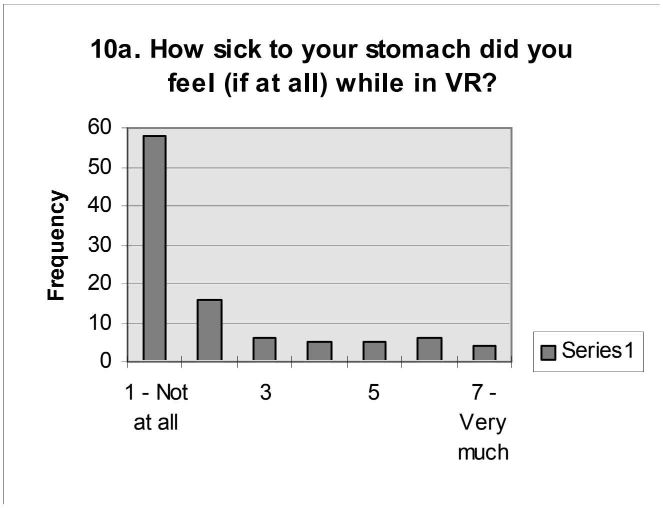


Figure 18 - Frequency distribution of sim-sickness data

The first question dealing with these issues asked the students how "sick to their stomach" they felt inside the virtual environment. As illustrated in Figure 18, above, 80% of the respondents answered between 1 - 3, indicating that they did not feel at all sick to their stomach. At the high end of the spectrum (5 - 7), 15% indicated that they did indeed feel nauseous during their virtual experience. 5% of the respondents answered a 4, which might mean they experienced some nausea.

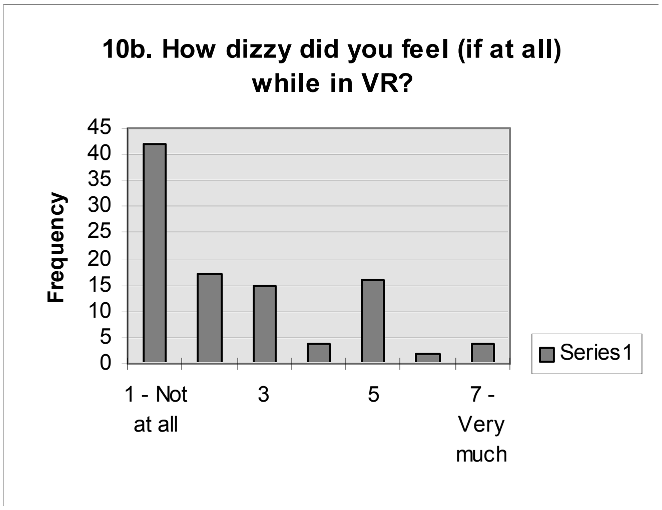


Figure 19 - Frequency distribution of dizziness data

When asked how dizzy they felt in the virtual space, as illustrated in Figure 19, above, 74% of the respondents answered on the low (1 - 3) end of the scale, indicating no or very little dizziness. 22% of the respondents answered on the high end of the scale (5 - 7). We were very careful to keep the students in a small area, where movement was minimized. Yet, it is clear that the technology does not provide a physically comfortable experience for, in this case, nearly a quarter of the subjects. However, 92% of the respondents wanted to go back into a virtual environment, regardless of physical discomfort.

4.1.4.6. "Presence" Analysis

"Presence" is the perceptual and somatic sense of being in a particular place (Hoffman et al., 1996, Prothero, et al., 1995; Prothero & Hoffman, 1995). Generating a sense of presence is one of the key features of virtual reality, and is facilitated primarily through encompassing the visual field in a relatively natural manner, to preclude alternative perceptual input from confounding or confusing the experiencer.

The Division headset is a full helmet, part of the ‘immersive system’ gear complement provided by the manufacturer. It weighs 7 pounds, and has a subtended view of about 150 degrees. Research has indicated that the minimum field of view requirements needed to generate a sense of presence is approximately 110 degrees. (Prothero, et al., 1995; Furness, 1986, 1989) In addition to field-of-view issues, the frame rate of the display is also a key component in generating a ‘natural’ feel to the display. When the frame rate gets much below 30 frames per second, the virtual motion perceived in the headset can get very jerky and unnatural. Furthermore, screen flicker is perceptually distracting, contributing to a lack of a sense of presence.

The virtual environment, at least at this stage in the development of the field, is still ‘cartoony’; most of the objects are not exact replicates of what we might expect. Organic material is particularly difficult to replicate, and the wetlands environment is rife with it. Yet, these environments were compelling enough to engage the students in such a manner as to temporarily ‘suspend their disbelief’, even in the noisy portable in which we conducted the experiential portion of the study.

Interestingly enough, it was in the ‘presence’ questions that we derived our most ‘normal’ distributions. All of the hype aside, subjects were able to articulate whether they really felt as if they were in their wetland environment or not. As all three of the questions’ distributions are so evenly matched, this data in particular has value. The other issue is whether a sense of presence is required in an environment such as this. It can be argued both ways; on one hand that a sense of presence means that the individuals perceptions are more ‘engaged’, leading to a deeper experience. On the other hand, even if an individual doesn’t perceive him or herself to be in a separate reality, it may make it easier to transfer what has been learned back out into what we normally consider “reality” (Hoffman, Hullfish & Houston, 1995).

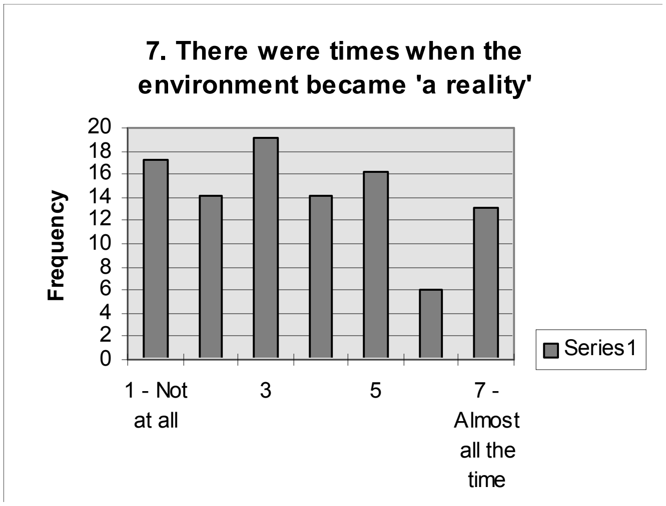


Figure 20 - Frequency distribution regarding a sense of presence (I)

In Figure 20, above, subjects were asked if their wetland environment ‘became a reality’ for them; and if ‘they forgot the real world’. Just over 50% of the respondents answered between 1 - 3, indicating that the virtual environment did not become a reality for them, or that they did not forget the real world. Another 14% of the respondents answered 4, indicating a neutral view on whether the environment was perceptually ‘real’ or not. The remaining 36% felt that, at least at some level, the virtual space was an alternate ‘reality’. Of that 36%, 13.1% answered 7 - almost all the time, whereas 17.2% answered 1 - not at all.

The graph is more heavily weighted toward the low end, indicating that most of the subjects did not feel that their virtual environment constituted a separate reality, or that they forgot the real world while they were in the virtual environment. In truth, these two issues should have been separated into two questions. However, as has been seen in other sections of this survey analysis, this lack of a sense of presence did not impede their learning or enjoyment. Later data from the VRRV project, however, indicates that enjoyment is often strongly related to a sense of presence. (Winn, 1995).

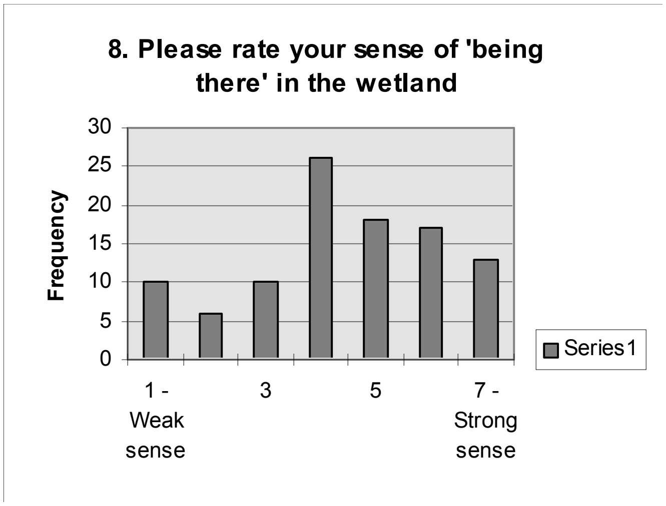


Figure 21 - Frequency distribution regarding
sense of presence (II)

In asking the subjects whether they felt as if they were in the wetland, we see an interesting shift towards the high end of the scale. As illustrated in Figure 21, above, 48% of the respondents answered 5 - 7, indicating a relatively strong sense of being in the wetland environment, which is different than asking if the wetland was real or if the real world 'went away', as discussed above. This could relate to Zeltzer's (Presence, 1992) distinction between interaction with an interface, which he calls 'presence' and interaction with content, which he calls 'logical interaction'. 26% answered with a 4, indicating that they perhaps had a moderate sense of being in the wetland environment. At the low end of the scale (1 - 3), another 26% of the subjects answered that they had a very weak sense of being in the wetland.

What this means is that even though subjects may not have actually perceived the virtual environment to be real, they still got a sense of being in the virtual wetland. This could be because they had built one of the environments and were looking for the aspects of the environment that they had designed. It could also be due to familiarity with expected objects in the virtual wetland. All subjects in a particular group knew what was going to be 'in' their space, and so might have been more inclined to see the space as a wetland, even an imagined wetland as it was.

The frequency distribution for the last presence question, on whether subjects felt they were in a ‘different place’ (neither real nor unreal) is illustrated in Figure 22, below.

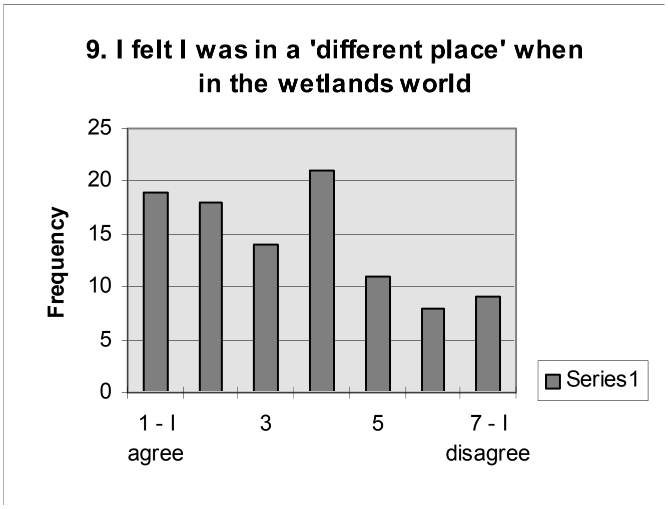


Figure 22 - Frequency distribution regarding presence (III)

This graph is very similar to the graph illustrated in Figure 19. The question was asked to assess a general sense of presence. 51% of the respondents answered 1 - 3, indicating that they perceived they were indeed in a ‘different place’. 21% of the respondents answered 4, indicating they neither agreed nor disagreed that they were in a ‘different place’. At the high end of the scale (5 - 7), 28% of the respondents disagreed with the statement, indicating that they did not feel like they were in a ‘different place’.

This data support the findings reported for question 8, regarding the sense of being in the wetland. Instead of a sense of whether the environment was real or not real, or whether the ‘real’ world was no longer perceived, it seems clear that some of the subjects felt present in the wetlands environment, and that they felt that environment was ‘different’ from the real world.

4.1.4.7. Essay Question Analysis

There were two essay questions on the Satisfaction Survey:

9. Overall, what did you like BEST about this Virtual Reality Project?

10. Overall, what did you like LEAST about this Virtual Reality Project?

We received responses from 97 of the participants, most of whom answered both questions. Responses were analyzed according to the following categories, listed in Table 15, below:

Table 15 - Survey Essay Response Categories

LIKED BEST	LIKED LEAST
1 - Building	1 - Difficulty Building
2 - Experiencing	2 - Difficulty Experiencing/Simsickness
3 - Building and Experiencing	3 - Difficulty Building and Experiencing
4 - Final Product/Sense of Completion	4 - Didn’t get to program final product
5 - Overall Process	5 - Didn’t like overall Process
6 - Focus on Hardware Aspect	6 - Not Enough Time!
7 - Educational Focus	7 - Educational/Research focus
8 - Negative Comments	8 - Positive Comments
	9 - Group Issues
	10 - Misc. Response

Frequencies from the first question, regarding what subjects liked BEST about the virtual reality project are illustrated in Figure 23, below.

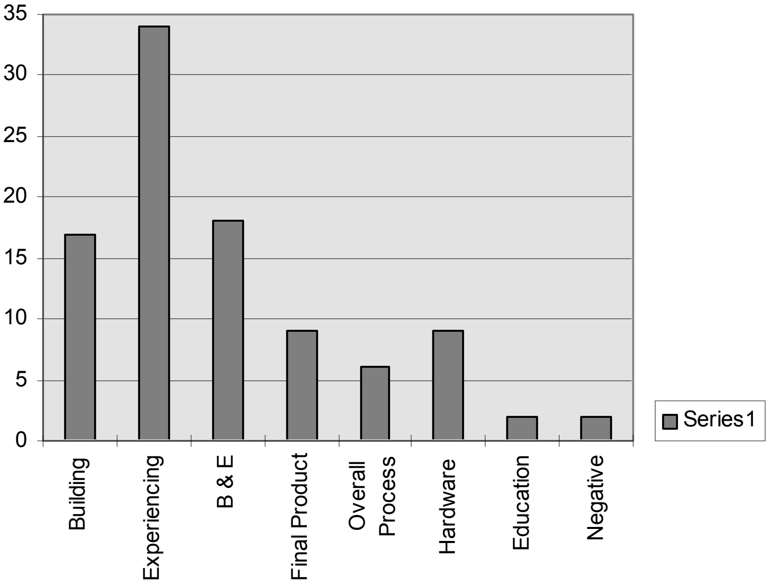


Figure 23 - What students liked best about their virtual reality experience

As can be seen from the graph above, the bulk (*n* = 34) of the positive responses were regarding the experience of visiting the virtual wetlands. This was to be expected, since the reward for learning about the wetland environments was to experience the students' creations.

Other children preferred either the building process (*n* = 17), or enjoyed both building and visiting their environment (*n* = 18). Nine of the subjects said that they liked the final product best; the sense of accomplishment of finally getting to view the product which they had been working on so diligently. The overall process was listed as the best component by six of the subjects, whereas nine subjects focused their attention on the hardware itself, mainly the use of the helmet.

Two students indicated that learning about wetlands was for them the best aspect of the project, and two students did not like anything about the project whatsoever. It is interesting to note that in both these cases, the students' partner was not present for the bulk of the project. In the second essay question, regarding what they liked the least, both students mentioned the lack of a partner as being highly detrimental to their enjoyment of the project overall.

It is clear that most of the positive responses (*n* = 69) had to do with activities directly associated with either the development process or the experiential component of the project, or both. It is unfortunate that more students didn't have an appreciation for the educational portion of the project (*n* = 2).

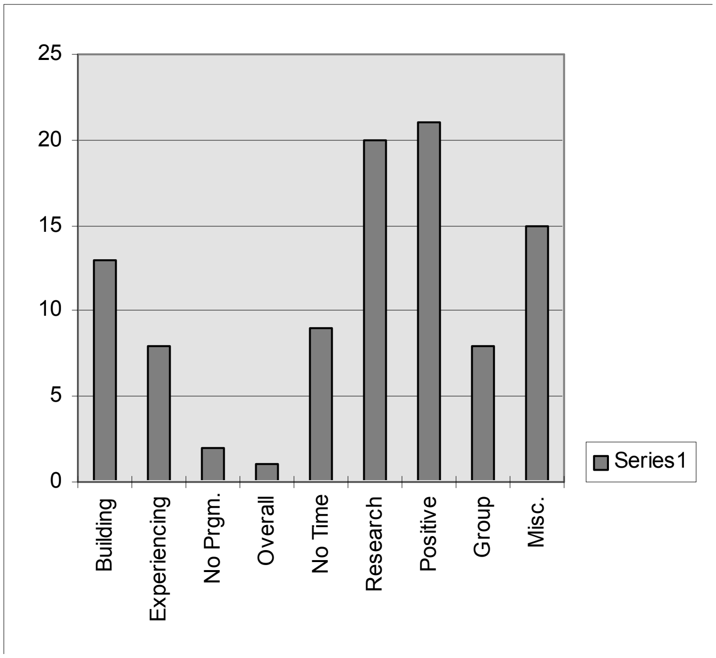


Figure 24 - What students liked least about their virtual reality experience

This point is reinforced by the data from the second essay question, illustrated in Figure 24, above, in that the bulk (*n* = 20) of the negative responses were about the students' dislike of the research or bookwork component of the project. However, it is clear from the test scores that indeed, the children learned, perhaps in spite of themselves!

Negative aspects of the project that were mentioned by subjects include building the objects and world (*n* = 13), not enough time (*n* = 9), experiencing VR (*n* = 8, including 4 specific references to simsickness), a negative group or partner experience (*n*

= 8), and fifteen miscellaneous comments, ranging from “Having to wait to see the finished product”, to “The talking of the teachers”.

Many children (*n* = 21) answered that there was absolutely nothing that they would have changed about the project, making comments such as “I don’t think there was anything wrong with it; I had lots of fun!”, and “Nothing. There was nothing in my opinion that I didn’t like.”

4.1.4.7.1. Survey Essay Question Summary

It is a continued affirmation of the value of the project that all of the subjects, except two, had positive feelings to report as illustrated in Figure 23. Out of the 97 responses on the second essay question, illustrated in Figure 24, 21 of the subjects wouldn’t have changed anything, leaving 76 respondents who had, for the most part, a single negative comment to make.

It appears that the virtual environment design process, and experiencing the subjects virtual creations was viewed as the most valuable aspect of the project. It also appears that 20% of the students who responded did not like the research or bookwork component of the project. These students did not make the connection that the research component was just as important as learning how to create objects in 3-D, or how to define and refine the interface for learning.

4.1.5. WORLD BUILDING VS. EXPERIENCING: A COMPARISON

A post-hoc analysis was performed was with regard to the value of world building versus the experiential portion of the process. Because measures were collected for 21 students who went through the entire world-building experience but did not don the helmet and experience their creation, comparisons could be made between these students’ test scores and those students who both took part in the world-building exercise, and got to experience two worlds as well.

By conducting a between-subjects ANOVA on the objective test scores, no significance between world-building and experiencing was found $F(1, 81) = 1.54$, $p > .05$, as presented in Table 38. Further analysis yeilded a significant pre-post effect,

$F(1, 81) = 78.14$, $p < .001$, and no interaction effects, $F(1, 81) = .35$, $p > .05$, as presented in Table 39.

In performing the same analysis on the concept map data, *slight* significance was found between students who got to experience virtual reality versus those who did not $F(1, 65) = 3.22$, $p < .10$, as presented in Table 35. Additional analysis yeilded a significant pre-post effect $F(1, 65) = 54.08$, $p < .001$, and no interaction effects $F(1, 65) = .13$, $p > .05$, as presented in Table 36.

In a further within-subjects ANOVA comparing concept map data for built vs. chosen representations coupled with the virtual reality experience variable, no significant difference for main effect was found $F(1, 65) = .13$, $p > .05$, and no interaction effects $F(1, 65) = .06$, $p > .05$, as presented in Table 37.

Based on these results, it appears that the primary cause for the substantial pre-post improvement in scores can be directly attributed to educational treatment as opposed to experiencing the virtual environment. However, it was the experiential portion of the project that was highly motivating for most of the children. The reward of seeing what they had worked so hard to create was an end-goal that was clearly defined and achievable based on the students' own hard work. The students who didn't get to experience their environments were very disappointed. Therefore, even though the experiential portion of the project did not affect the students cognitive measures it was a critical affective component to the project.

CHAPTER 5: DISCUSSION

5.1. DISCUSSION OVERVIEW

In this chapter results of the research are reviewed and discussed, and opportunities for future research are presented. The chapter ends by describing pertinent points valuable to anyone considering virtual environment development in the classroom.

5.1.1. FINDINGS AND HYPOTHESES: AN OVERVIEW

The original hypotheses were that the Constructivist learning paradigm would be more educationally valuable than the Traditional learning paradigm, and that both Constructivist and Traditional learning would both be more educationally valuable than the No Instruction treatment.

What the data indicates is that the Constructivist and Traditional educational approaches were not significantly different from one and other, but that the Constructivist approach did provide results that varied significantly from the No Instruction treatment. Lastly, there was no significant difference in the scores between the Traditional and the No Instruction treatments.

5.1.2. REVIEW OF THE FINDINGS

This study utilized four measurement tools: Quantitative tests, Concept Maps, Interview data and a Survey. The VRRV team also spent a great deal of time discussing the project with teachers and students alike, providing a fifth set of observations that is more qualitative in nature. These qualitative observations are included in the section entitled “Other Observations”.

5.1.2.1. Quantitative Measures

Results from the quantitative test indicated significant improvement between pre- and post-test measures for all groups, but it was unclear from these results which treatment(s) might have been more effective as both the Constructivist and Traditional treatments produced significant improvements. However, it was clear from this measure that students, regardless of treatment had learned enough declarative knowledge about wetlands ecology to improve their scores significantly.

5.1.2.2. Concept Map Measures

Concept Maps were drawn by the children for both their built and chosen worlds. All students provided Concept Maps for the virtual environment that they created and an additional Map for a cycle of their choice (other than their built environment).

Concept Map analysis was conducted to ascertain which treatments were more educationally valuable. Statistically significant improvements were found between pre- and post-test measures for all treatments regardless of group. Significant differences were also found between scores on the world that children built versus the world that they chose to represent and interactions between all of the above.

In comparing separate treatment data, Constructivist and Traditional treatment results did not vary significantly from one another. However, Constructivist scores were significantly better than the No Instruction scores. These differences can be attributed to the amount of attention paid to learning the cycle under the Constructivist treatment in comparison to the No Instruction treatment.

The Traditional and No Instruction results did not vary significantly from one another. These measures were both taken on “chosen” concept map representations rather than on “built” (Constructivist) representations. The lack of significant treatment differences can be attributed to the fact that most students, whether in the Traditional or the No Instruction treatment had chosen to represent the water cycle, a cycle already known to many of them. Therefore, there was a ceiling effect to the amount of additional knowledge students could have about the water cycle.

However, it was found that the world building process had a substantial effect on all of the students. Cycle representations on the pre- and post-tests differed substantively. Pre-test representations were primarily verbal, whereas post-test representations were primarily visual or a visual-verbal mixture. In many cases, students represented objects directly from their virtual environments, using them to describe the wetland cycle they had built or experienced. There seemed to be an increased sensitivity to both the visual components and the relationship between those components as they related to the particular cycle described. Further interpretation of all treatment results can be found in section 5.1.3.

5.1.1.3. Interview Data

Interviews were conducted with each student as they left a virtual environment. Measures were taken for both built and experienced environments. Interviews were intended to capture the student's understanding of that particular cycle based on his or her experiences in that environment.

Quantitative analysis of the Interview data indicated that there was a significant difference between groups, and between whether the students were describing the world that they built, or one that they experienced but had been built by other students. Most students described their created environments very well, and could transfer their description skills to articulating what had transpired in the world they experienced but did not create. However, the significant differences seen between 'built' and 'experienced' could be partially attributed to the lower 'experienced' scores for the Carbon group, in which students, including 3 of which were learning impaired, experienced Nitrogen, the most chemically complex and abstract of the four cycles studied and presented.

5.1.1.4. Survey Data

Students indicated they very much enjoyed the "Virtual Wetlands". They liked both building and visiting their environments, and wanted to incorporate the use of virtual technology into the curriculum for students who would be studying this subject in the future. Almost all of the students wanted to experience virtual reality again. However, it is difficult to ascertain how much of this positive attitude can be attributed to the novelty of the technology rather than its' true educational usefulness. Additional ongoing research needs to be conducted so that the technology becomes an integral part of the standard curriculum rather than a once-a-year interactive treat.

Regarding process, most students indicated that they worked collaboratively with their partners, and with their larger (8-10 member) group. This collaborative work environment was one of the primary reasons that this project was a success; if students had been working individually, it would have been very difficult, if not impossible, to develop cohesive, consensually meaningful environments.

Most of the students believed that the project was intended as a means to provide a teaching tool for other students. This dovetails with the way the project was initially described to the students; we told them they were to become instructional designers, who were to determine how best to convey their particular cycle using virtual reality as a learning tool. Most felt that they had learned about the wetland environment from a combination of their own exploration, coupled with material presented by the traditional science teacher.

Most students understood exactly what they were to accomplish while in the virtual environment, and also felt that the task was not difficult to accomplish. They also felt that using virtual reality to study wetlands ecology would be the ‘best’ way for next year’s students to learn about the subject. Almost all (92%) of the students wanted to experience ‘virtual reality’, i.e. both world building and experiencing, again.

Regarding physical discomfort, most of the students felt neither dizzy nor sick to their stomach while in the virtual environment, though some reported they experienced some degree of dizziness or nausea.

The ‘presence’ data indicated that though students ranged widely regarding their sense of being in another place that felt ‘real’, there was a moderate trend towards feeling as if they were in their wetland, or at least in a ‘different place’, regardless of whether it was real or not.

Regarding what students liked best about their virtual reality experience, the top three answers were experiencing their environments, building their environments, or both. Negative comments (things students liked least) were research, building the environment, and not having enough time to complete their tasks the way they would have liked. These last two items, from my experience, are tightly coupled.

5.1.1.5. Synthesis

These four data sources: quantitative, concept map, interview and survey seem, at first glance, to be quite discrete. However, these four measures provide an interwoven perspective of that individuals' understanding of declarative, relational, procedural and affective information. The measures were designed to uncover different aspects of the students' experiences. As a whole, however, the data provide a comprehensive picture of the students' experience during that two week period from both a cognitive and affective perspective.

In addition, this study directly assessed the value of virtual environment creation as a means of demonstrating the students' understanding of the concepts and interactions in the wetland environment. The construction process *was* the performance task; the two could not have been more tightly coupled. Students were free, within the time constraints of the project, to continue to improve upon their contributions.

Overall, there were significant gains in knowledge acquisition, as measured by all of the instruments. What the students learned traversed a wide field: wetland ecology content, aspects of the design and development process, visualization skills, modeling, and development, translation of verbal and text-based information into a visual narrative form, the rudiments of instructional design and further experience in the process of inquiry.

The objective measures provided input on the children's declarative knowledge acquisition, the concept maps provided a complementary form for illustrating their relational knowledge and the interview process provided perspective on students' procedural knowledge. Students described their experiences in narrative form (Bruner, 1990), placing themselves at the center of their experiences. The survey information provided information on what aspects of the process worked for the children, and what aspects were troublesome. This was our most comprehensive source of affective information, in that we discovered how children felt about their experiences.

What emerged from looking at the data as a whole was the importance and centrality of self and self-in-action during the learning process. These students were highly motivated to learn and to experience this new way of assimilating and sharing content. They were, as Scardamalia, et al., (1989) and Bruner (1990) would term "intentional" learners, in that their internal motivational state was directed towards the learning process. They were also empowered learners (Brooks & Brooks, 1993), actively and consciously engaged in the design of their knowledge structures. This became apparent in reviewing the Interview data particularly. Students described their experiences using phrases such as "*I* took the nitrogen and put it into the storm cloud", rather than "Nitrogen can be fixed during electrical storms." They embraced their role in making these cycles work. Even though they realized that these cycles happen without human intervention in the real world, having been personally responsible for them in the virtual world made the cycles more meaningful for the students.

The combination of creating icons, indexes and symbols coupled with the experiential component led students to reason abductively (Cunningham, 1992; Shank, 1992; Shank et al., 1994) about the relationships between objects and interactions. Evidence of signs used in abductive reasoning within the students' virtual environment abound. For example, Carbon World was designed to illustrated the oxygen-carbon dioxide cycle. Students chose one visual representation for oxygen (blue spheres) and another for carbon dioxide (double red spheres). Transpiration was represented by the mixing of carbon dioxide and a plant, resulting in the visual creation of oxygen. Respiration was represented by the mixing of oxygen and an animal, resulting in the visual creation of carbon dioxide.

Students designed the environment so that each time an organism connected with the right molecule that it needed for either process, the visual by-product of the process would appear, leading the students to understand that whatever had been mixed together was correct. The abductive component of this experimental process is presented in the in the partial list of outcomes, illustrated in the examples below:

Example 1:

1 Primary Sign: Oxygen

Secondary Sign: Animal

Object: Respiration

Abduction: Oxygen is what animals need to breathe, and to create carbon dioxide as a by-product of respiration.

Example 2:

2 Primary Sign: Animal

Secondary Sign: Oxygen

Object: Respiration

Abduction: Animals need oxygen to breathe, and to create carbon dioxide as a by-product of respiration.

When students would attempt to understand the process of respiration, they could either start with the animal, or start with the oxygen molecule, and still derive the same outcome. The abductive process became even more complex when students tried to understand the relationships between transpiration and respiration, and oxygen and carbon dioxide. They mentally formed a table of the relationships, based on experiencing their hypotheses. The relationships between the oxygen and carbon dioxide molecules and their related processes was ongoing. Students could continue to test their hypotheses at will, until they constructed a working model of the relationships in their mind. It is this ongoing nature of the virtual representations and the relationship between them that made these wetland environments abductive learning tools.

A key element of abductive reasoning is to allow students to experiment with their assumptions. All four of the environments allowed students to test their hypotheses about relationships by interacting directly with the objects in the environment. However, two (Carbon, descibed above, and Energy) were more clearly suited to running the cycle from both a deductive and inductive perspective, by allowing students to make assumptions about the represented cycle that weren’t strictly procedural. Students could enter the cycle at any point, and continue forward without having a clearly defined starting and ending point. This open-endedness helped students develop a richer sense of the cyclical nature of the process.

The distinction between icon, index and symbol can be seen in the representations students selected. Iconic representations were direct analogs for the physical world, such as clouds, rain and a pond. Index object examples include the spheres representing carbon dioxide and the oxygen present in the Carbon environment. These chemical representations indexed the presence of both respiration and transpiration in the environment, without having to visually represent the processes themselves.

The symbolic language developed by these students encompassed all of the interactive relationships established in the environments. In some cases, the interactions created auditory tones that represented correct and incorrect interactions. Correct actions yielded visual feedback in addition to the positive auditory tone. Incorrect actions yielded the negative auditory tone, but did not provide any visual feedback to the student. Interestingly, all of the students in the project had deeply held convictions about tonal properties, based on their previous computer experience. Correct-action sounds had a bell-like tone, incorrect-action sounds were selected based on their similarity to the sound presented by a MacIntosh computer when a user tries to complete an invalid operation. The representations were surprisingly consistent between groups, indicating at least some level of consensual meaning was attached to both tones, and to the presence or absence of visual feedback.

In using sign theory as a form of alternative assessment, it was possible to evaluate the students’ experience as a whole. Sign theory presents a means of understanding how signs are developed and linked. Though a rubric could be developed to assess the individual value of students' signs, it would be inappropriate within the context of this particular study. Students collaborativelydeveloped an environment, rather than singular representations. Holistic thinking was encouraged, rather than individual competition in building the best individual object for the environment. Furthermore, the technology limited the complexity of student representations. Objects had to be simply designed and colored, due to memory and processing limitations. This did not lead to the development of vastly complex or intricate representations. Students focused instead on providing meaningful interactions between their relatively simplistic representations. The establishment of cause and effect relationships that made sense within the context of the cycle presented was the primary means of conveying meaning within the four virtual environments. Examples of students' signs, indexes and symbols are contained in Table 16, below.

Table 16 - Use of Icons, Indexes and Symbols in Kellogg Middle School Wetland Environments

ENVIRONMENT	ICON	INDEX	SYMBOL
CARBON Learning Objective: To develop an understanding of the processes of respiration and transpiration	Pond, Sun, Fish.	Duck representing all birds, Alligator representing all reptiles, Frog all amphibians, Dragonfly all insects, carbon dioxide molecules as all carbon dioxide, oxygen molecules as all oxygen.	Carbon dioxide molecules, oxygen molecules, interactions between virtual objects representing transpiration and respiration.
ENERGY Learning Objective: To develop an understanding of the food chain, and how energy moves through the wetland ecology system.	Pond, Sun, Dragonfly, Water Lily, Cattail.	Blue-green algae representing all lower plant life, Fish and Duck representing herbivores, Turtle, Coyote, Snake and Frog carnivores, Alligator as omnivore.	Symbolic interactions between virtual objects resulting in positive and negative feedback to the student, as student attempts to enact the food chain.
NITROGEN Learning Objective: To understand the circumstances under which nitrogen is fixed in the wetland environment, how nitrogen moves through the environment, and how fixed nitrogen can be denitrified through decomposition and other processes.	Pond, Sun, Fish, Bird, Dragonfly, Cattail, Lily, Frog, Turtle	Lightening bolt as electrical energy, Nitrogen molecules as all nitrogen molecules, Fixed Nitrogen as all fixed nitrogen molecules,	Symbolic interactions between nitrogen molecules and the energy, nitrifying bacteria, and between fixed nitrogen and the Duck, and between Duck and Fox, Nitrogen molecules, Fixed Nitrogen molecules, Nitrifying bacteria as fixing agent, Denitrifying bacteria as decomposition by-product
WATER Learning Objective: To understand the components and processes associated with precipitation, condensation, and evaporation.	Pond, Cloud, Rain, Frog, Turtle, Cattail, Lily, Fish, Bird, Dragonfly	Lightening bolt as energy from the sun, rain movement representing all forms of precipitation.	3 upwardly pointing arrows representing evaporation, cloud color representing condensation

Regarding the abductive reasoning component, an example from Carbon World is included in Table 17, below.

Table 17 - Example of a Deductive, Inductive, and Abductive Syllogism

ENVIRONMENT	DEDUCTION	INDUCTION	ABDUCTION
CARBON Learning Objective: To develop an understanding of the processes of respiration and transpiration	Sign1: Molecule 1 Sign2: Molecule 2 Sign3: Animal Sign4: Plant Object: Respiration Hypothesis: All animals need oxygen for respiration. Interaction: Mix Molecule 1 with an animal, resulting in the appearance of a different kind of molecule (Molecule 2). Deduction: Molecule 1 must have been an oxygen molecule, providing the animal with air for respiration.	Sign1: Molecule 1 Sign2: Molecule 2 Sign3: Animal Sign4: Plant Object: Respiration Hypothesis: Molecule 1 (oxygen) interacts with animals. Interaction: Mix Molecule 1 with animal resulting in the appearance of Molecule 2 Induction: Since the animal accepted Molecule 1, we can infer that respiration took place. Therefore, all Molecule 1's must be oxygen.	Sign1: Molecule 1 Sign2: Molecule 2 Sign3: Animal Sign4: Plant Object: Respiration Assumption: Respiration requires oxygen molecules and results in the creation of carbon dioxide molecules. Interaction: Mix Molecule 1 with animal to see the result. Form next hypothesis, and test again, and so on. Conclude that there is a relationship between the specific Molecule 1's and the object. Continue testing with Molecule 2 and animal interactions. Is the result the same? Test Molecule 2 with plants. What are the results of this interaction? Abduction: Molecule 1 works with animals, resulting in Molecule 2. Molecule 2 works with plants, resulting in Molecule 1. Animals respire, so Molecule 1 must be oxygen. Plants transpire, so Molecule 2 must be carbon dioxide.

It also became clear that students constructed culturally mediated stories; that they found a room for their individual contributions within the development of a communal voice, which gave rise to what was in essence a visual, interactive language that has meaning, particularly to the group who created each individual environment. To be respected as an individual, to be heard, is as Coles (1989) describes, one of the most elemental aspects in the development of self worth. He states:

> Their stories, yours, mine-- it's what we all carry with us on this trip we take, and we owe it to each other to respect or stories and to learn from them. Such a respect for narrative as everyone's rock-bottom capacity, but also as the universal gift, to be shared with others, seems altogether fitting. (p. 30)

In fact, each individual data set for each student tells a slightly different story. It was clear from the results that different students reacted differently to the project, that they had indeed constructed an understanding of their own, that was illustrated on the pages and video tapes that we collected. But most importantly, that understanding resided inside each individual and the collective memory of the group.

5.1.3. TREATMENT DISCUSSION

In this section, interpretation of treatment results from concept map analysis are provided.

5.1.3.1. Interpretation of Constructivist vs. Traditional Treatment Findings

The reasons for the lack of significant distinction between the Constructivist and Traditional treatments could be attributed to the following:

11. These students were already constructivist learners, even when taught traditionally.
12. There was so much to learn under the constructivist treatment that the students may have been experiencing cognitive overload.
13. The potential for superior learning in a virtual environment is related to a high degree of presence, which was lacking along some dimensions for most students.
14. Exposure to the virtual environment was brief (< 5 minutes), and navigation and interaction was difficult for some students.

15. Cognitively able students learn regardless of pedagogical considerations.

Regarding the students' daily classroom activities, these students took part in thematic, cross-subject, project-based learning as described by Zemelman, Daniels & Hyde, (1993) and Brooks & Brooks (1993). In fact, the case can be made that these children were already richly steeped in both collaborative and individual learning opportunities. They were living the kind of inquiry-based learning practices espoused by both Cunningham (1992) and Shank (1992, 1997).

In asking these students to learn two of the four cycles in the 'traditional' classroom, using traditional teaching tools (lecture, textbooks, and worksheets), it is possible that the students took their day-to-day learning practices from the constructivist classroom into the traditional classroom with them.

In fact, the only additional aspect of constructivist learning that this project brought to these students was the opportunity to be the designers of a knowledge base from the ground up; to learn how to use the technology, to model in 3-D, to consider how to design and develop an interactive educational environment, and to embody textual information in a visual format. However, this was a formidable task. It could have been that there was too much world-building activity, negating the students' ability to absorb more content information during their constructivist treatment sessions.

This relates to the second point in the list above, that students may have been experiencing cognitive overload. The most common complaint about the project was that students felt they did not have enough time to adequately design, develop or experience their environments. Data should have also been collected on whether students felt they had enough time in the traditional classroom. Survey results indicate that students disliked the research component of the project the most. In the traditional classroom, they were almost spoon-fed the answers. For example, the worksheets had page numbers for reference on them. In comparison, students had to look up everything of relevance themselves in the constructivist classroom, in addition to all of the other skills that they were learning.

It remains to be seen what students can *do* when they do have enough time. We have yet to be in a classroom environment where we were not in a rush to get everything done within a very tight time schedule. Others studying the effects of virtual learning environments (Dede, et al, 1996; Loftin, et al, 1993) have had more leeway over their development schedules, leading to a different set of issues that they have been able to more adequately address.

Survey results regarding the experiential portion of the project indicate wide differences amongst students regarding their sense of presence. Subsequent research indicates that superior learning in a virtual environment is tightly coupled to a high degree of presence and that when the sense of presence is reduced, so is the opportunity for learning. (Winn, 1995).

Students' sense of presence in this study may have been limited due to lack of experience in the virtual environment. They had no opportunity for practice in a virtual environment, so that the first time they went into their virtual space, they also had to learn how to navigate and interact with virtual objects. This is not a good way to introduce students to a virtual learning environment (Moshell, 1995). As is true with computer-based interface, if you are too busy playing with the buttons, you can't really enjoy the show (Kay, 1990; Laurel, 1990).

Regarding high-ability vs. low-ability students and the effects of virtual environment construction and experience, Winn (1997) has found that low-ability students, particularly male low-ability students, benefit most from the kind of constructivist approach followed in this study, and that high-ability students tend to learn regardless of the teaching style or classroom environment. Low-ability students often require either additional time or assistance to complete their tasks when designing virtual learning environments (Winn, 1997). However, in this project almost all of our students were either average or above-average ability, and most were also highly self-motivating, as described in the KCOT program application. (Kellogg Middle School, 1996). We had only three low-ability students, and those that we did have were all in the Carbon group. The pre- and post-test results of the Carbon group were consistent with Winn's (1997) findings for the world-building portion of the project.

In interpreting the concept map data more broadly, it should be mentioned that the process of performing visio-spatial exercises, such as drawing, modeling, and visualizing objects in three dimensions coupled with actually modeling objects on the computer had a profound affect on students' concept map representations and on the depth of understanding associated with the wetlands processes they represented. As described by Samuels & Samuels (1975), Morris & Hampson (1983), and Adams (1989), imagery is an essential tool used to understand visual and spatial relationships. Furthermore, the process of translating information between symbol systems (Mones-Hattal & Mandes, 1996; Adams & Hamm, 1988) results in the utilization and enhancement of one's higher level thinking skills, as described by Bloom et al. (1956).

As stated by Cunningham (1992; 1997), signs can be highly independent of what they reference. As is true of developing any tightly-woven referential system, the more signs that link to objects of interest, the better recall an individual has. If this study has provided these students with the opportunity to utilize their visualization skills more fully, by providing alternate access to information, then it has been successful. The increased use of pictorial and diagramatic concept map representations may well be a sign of this success.

Students had least difficulty developing representations about concrete, physical relationships, even though the icons and indexes used to represent these relationships were somewhat abstract (lightening for energy, fox for all carnivores, etc.) The students definitely had a more difficult time considering chemical relationships, and how to represent them. Discussion about the representation of oxygen or nitrogen took at least twice as long as did discussions about the representation of water vapor or algae.

In teaching young people physics, Minstrell (1992) finds students have a strong attachment to specific (physical) objects and to less developed modes of reasoning during their younger (pre-teen) years. As they grow older, their ability to develop abstract representations becomes more pronounced; findings similar to those presented by Perkins (1993). It is this ability to *abstract* that adds rich new dimensions to the meaning-making process (Cunningham, 1992).

Finally, there was insufficient time to properly provide students with deep lessons and practice in abductive reasoning (Cunningham, 1988; Shank, 1989), which may also have led to the lack of differentiation between the constructivist and traditional treatments. The original intention had been to take the time for iterative design, and to provide students with an opportunity to teach each other and to teach non-KCOT students using their virtual environments. Both of these activities would have led to greater opportunity to develop hypotheses and to test one's assumptions about most aspects of the virtual learning environment. Unfortunately, the schedule did not permit this kind of deep, intensive inquiry.

5.1.3.2. Interpretation of Constructivist vs. No Instruction Treatment Findings

Significant differences were found between the constructivist and the no instruction treatment results, as expected. Even with the overlap between cycles, it was expected that students receiving no instruction in a given cycle would certainly do less well than those receiving instruction of any kind.

Of course, this was not the case in comparing the traditional vs. no instruction treatments, as described below.

5.1.3.3. Interpretation of Traditional vs. No Instruction Treatment Findings

Another unexpected finding was the lack of significant difference between the traditional and the no instruction treatments. However, the concept map data, which provided me with the bulk of my treatment analysis information, was skewed by the preponderance of students drawing the water cycle. Students knew this cycle whether they were studying it or not, and it was definitely the cycle of choice for the 'chosen' rather than 'built' representation. Some students also knew the energy cycle, which enjoyed second-place billing for the number of 'chosen' representations.

There is no basis for a strong treatment-based comparison between the traditional and no instruction options. Had the depth of the students *a priori* knowledge of the water and energy cycles been known, compensating factors would have been put in place, such as constraining the represented (chosen) cycle to tie to one of their 'traditional' treatment cycles, or to have had students draw concept maps representing the cycle associated with all three treatments.

5.1.2.4. Other Observations

What the quantitative data do not describe is how very much the students' language and presentation techniques changed and grew over the course of the project. Students began to speak in terms of their 'perspective', and 'rotating their view'. They seemed more willing to consider part-to-whole relationships in their other classes. All four KCOT teachers noticed this trend.

The concept maps, as discussed above, show a clear movement towards the incorporation of visual metaphors in their post-tests, which can be attributed directly to their virtual environment construction process, as this was the only component of the project that included visual representations. It affected the manner in which students chose to represent information regardless of what instructional paradigm had provided the initial content.

Alternative assessment provided a means to get at the heart of what became meaningful constructions for both individuals and for each group. This became clear when working with the special needs students present in the KCOT classroom. For example, one very shy, intellectually challenged 12 year old girl managed to create a fox for Nitrogen World. This was her first "creation" or "performance" of the year; the first indication that she was able to construct understanding about a concept in a way that allowed her to contribute both to her personal knowledge base and to a larger, more collaborative construction.

This was a phenomenal accomplishment for her. However, when compared to the larger classroom of students, who were all contributing objects, providing constructive comments, and determining interrelationship possibilities, this one student didn't really measure up from a "performance" standpoint. However, in utilizing a variety of measures and by valuing the process of self review (Reif, 1990), students maintained their sense of self-esteem and motivation throughout the study.

5.1.3. OPPORTUNITIES FOR FURTHER RESEARCH

5.1.3.1. Overview

Findings indicate that there was no significant difference between the Constructivist and Traditional treatments. Though significant differences were not found between the Constructivist and Traditional treatments, nor between the Traditional and No Instruction treatments, subsequent research has been conducted that supports the original hypotheses put forth in this study (Winn, 1995, 1996, 1997; Taylor, 1997, Osberg, 1997; Dede, 1997). Additional research opportunities based findings discovered after completion of the VRRV project *in toto* have been included in a special addendum. Suggestions for additional research provided in this section of this chapter are based on findings specific to this study.

Teaching by traditional means is a well understood endeavor, as it has been the norm for hundreds of years. However, there is opportunity to further test the educational value of constructivist practices. If at minimum constructivist practices do no harm, they are certainly worth researching further. We should build on our understanding of what aspects of constructivist practice may provide additional value for the student. Therefore, this study provided a good starting point from which further research can be conducted into constructivist practices in the classroom, especially those utilizing virtual technologies as an adjunct learning tool.

It is clear from the results that students made meaning from their knowledge constructions under both the Constructivist and Traditional treatments. This is a semiotic issue. Students created and used icons, indexed and symbols extensively, and engaged in abductive reasoning, as presented in Tables 16 and 17, above.

Even though it is clear that students created rich visual and interactive representations, and reasoned abductively in their virtual environments, semiotic issues could have been more deeply addressed. Further research needs to be completed into the *nature* of the knowledge construction process, as described by Cunningham (1992), Shank (1989) Phillips (1995). It would be valuable to relate that process to the creation of both tangible and virtual objects, how they are developed, and how they come to have meaning, both as symbols and as directly accessible objects (Mones-Hattal & Mandes, 1996). In addition, a rubric could be designed to assess the richness of particular signs, and of sign systems. This could lead to the development of a more universal visual and interactive semantic that would have the potential to transcend cultural boundaries, while still allowing for individual creativity in the design and development of individual signs.

From a Constructivist perspective, additional research could be conducted on the general value of constructivist learning; learning for depth vs. breadth (Brooks & Brooks, 1993), how and when to incorporate visual and verbal representations (Mones-Hattal & Mandes, 1996), whole body learning and experiential education (Hutchins, Hollan, and Norman, 1986; Kraft & Sakofs, 1989), meaningful self-directed learning (Poplin, 1991), and examining one's reasoning for developing certain knowledge constructions (Minstrell, 1989; 1992; Minstrell, Stimpson & Hunt, 1992).

Metacognitive Issues

One goal of constructivism is to teach students how to effectively question the information placed before them. Pressley, Harris & Marks (1992) discuss the development of metacognitive strategies, as couched within a constructivist framework. Though there are those who believe that critical thinking skills can only be taught within the confines of a content domain, others feel that one can learn basic strategies that can be applied across content areas (de Bono, 1991; Salomon, Perkins & Globerson, 1991; Scardamalia, et al., 1989; Butterfield, Wambold & Belmont, 1973).

Process Issues

Another opportunity for additional research has to do with existing classroom practices. At Kellogg Middle School, the VRRV team worked directly with the four-classroom program that was already utilizing a constructivist approach to the learning process. An intensive three to four week program of this nature undertaken in a more *traditional* classroom environment might yield more substantial differences when comparing Constructivist and Traditional treatments. Since the Kellogg students were already used to learning in a constructivist fashion, it is quite likely they just kept on utilizing the perspective and the cognitive tools that they used in their regular classroom environment, regardless of treatment. If one were to conduct further research on the educational effectiveness of constructivism, it seems clear that the comparative value would be enhanced by starting from a more traditional position.

Understanding Virtual Reality as a Learning Tool

From a perceptual perspective, additional research could be conducted within the virtual environment itself, testing navigational paradigms, effective use of color and texture, spatial manipulations of scale and orientation, and the more prevalent and effective use of auditory and haptic feedback. Furthermore, research into developing meaningful virtual tools would be useful (Rose, 1996), as well as designing and testing new navigational paradigms. All of these opportunities involve the use of signs and metaphors to make meaning in a virtual space.

On the practical side, the access and administrative aspects alone require in-depth analysis if the world-building process and virtual reality technology are to ever become an integral part of the learning process.

5.1.4 OTHER ISSUES

5.1.4.1. Adding Depth to the Existing Study

There were also many areas where, with more time and human resources, additional depth could have been added. Some examples include:

- Providing students with an opportunity to teach others using their wetland environments, to see what would be meaningful when trying to share their environments with others.
- Providing extra time so that initial designs could have been prototyped, reviewed, and modified rather than having to go with the 'first cut' due to time constraints
- Using stronger assessment tools, that would have provided a more fine-grained analysis, particularly between treatment groups.
- Providing more opportunity for cross-group discussions, to help the students develop more robust environments
- Providing tools and conducting analyses that would have yielded a deeper understanding of the meaning-making process and its affective components, as opposed to the knowledge-construction process upon which we focused our efforts.

There is not a substantial enough body of research to ascertain exactly what makes a virtual environment useful and enjoyable, when to use virtual technologies rather than other media, and the circumstances under which virtual environments are better learning tools than any other way to come at the learning process. Additional understanding could be garnered in these areas by conducting research in the areas listed under the bullet points above.

5.1.4.2. 'Covert' Learning

Survey data indicated that the educational component of the process for some students was not as much to their liking as the creative and technical aspects. This sets the stage for a discussion regarding ‘covert’ learning. The teachers, and the HIT lab staff were diligent in their presentation of a balanced perspective regarding the value of both the educational and technical components of the project. For 20% of the respondents, the educational component was rated poorly. However, it is clear from the test scores that the subjects learned about wetlands, regardless of whether the educational component of the project was presented using traditional means, or learned using constructivist means. However, since all of the subjects experienced the constructivist/world building treatment, and most of the resulting concept map illustrations indicated that this treatment had a deep effect on how they represented information, it can be assumed that the constructivist/world building activities directly affected their learning process.

This raises the question of using the world building and experiencing component of the project as a motivator for covert learning. Specifically, using virtual environment development may be a useful tool for those students who perhaps do not like, or do not respond well to traditional classroom practices. Subsequent research has indicated that this is indeed the case; that world building and experiencing is especially motivating for lower functioning boys (Winn, 1995), and is also motivating, though less so, for higher functioning students. At Kellogg Middle School, this was shown to be true as well, with regard to the Carbon group, in which the three lower functioning students were placed.

Regardless, the Survey indicates that almost all students enjoyed most aspects of the project; that the positive aspects far outweighed the negative components of the project for most of the students. We often heard students say that they felt that the project was moving too fast; that there wasn’t enough time for them to accomplish what they wanted to accomplish. Even though only 8 individuals mentioned lack of time specifically on the survey, it was the complaint most often openly voiced; not enough time to learn all about the modeling software, not enough computer time to create all of the objects the children wanted to develop, not enough time ‘under the helmet’, or not enough time for the project as a whole.

5.2. CONCLUSIONS

In conclusion, results indicate that the world-building process, coupled with the opportunity to experience one's virtual learning environment is a powerful, motivating way in which to learn about wetlands ecology. Apparently the traditional educational environment provides an equally educational experience, given the way the research program was designed.

On the Constructivist side, findings indicate that by incorporating the student's creativity and design skills, metacognitive skills, freedom to make their own design and navigational decisions, and their whole body into the learning process, students have a very wide avenue of opportunity for cognitive, somatic and affective growth and experience. On the Traditional side, teacher-led lectures, textbooks, and worksheets appear to be equally educationally valuable.

The field on both sides of the fence is rife with opportunity for both research and development. We must test and re-test our assumptions and how they affect our developments, and to encourage and support student involvement from idea generation to usability assessment.

To this end, a two-pronged approach to additional research is presented that incororates traditional educational programs for the students who do not want to take part in a constructivist environment, and constructivist classrooms that incorporate virtual educational programs that allow students the opportunity to participate in and contribute to the development of a virtual educational network. As one female student from this project said: "I don't think we are ready for this technology; our teachers don't know enough about it yet." Shank (1992) would agree. But the *students* do. Interestingly, this is the method used by Kellogg Middle School. They provide 6 different tracks or programs that vary in type of instruction, use of technology, core course concentrations, and time on task.

Several students mentioned the difference between verbal presentation, and creating visual, interactive cause and effect relationships themselves. One male student said “I didn’t understand the nitrogen cycle when the teacher explained it. I do now!!”. A female student said “It’s harder to learn this stuff out of a book; here I could go with it as it was happening. *I* was in control!” Another male student said “I knew absolutely nothing about this prior to building my world in VR. I used it to learn. I learned a process. It was fun, so I’ll remember it more.”, and another said “I understand it better now that I’ve experienced it.”

However, 20% of the students did not like the research component of the project. It would have been good to have conducted some visio-spatial testing prior to starting the project. It has been found (Winn, 1997) that high spatial students enjoy and value their virtual experiences highly. It would have been interesting to see if high spatial students correlated with those finding the research process onerous. If so, perhaps using the technology as a motivator is a completely valid approach to balancing a students verbal and visio-spatial development.

All of the students wanted *more of everything*; more time, more realism, more water, more mud, more animals and plants, more behaviors, more sound, more applications, more environments. I for one intend to try and give it to them.

ADDENDUM

ADDITIONAL RESEARCH OPPORTUNITIES BASED ON SUBSEQUENT RESEARCH RESULTS

As mentioned at the beginning of Chapter 5, subsequent research has been conducted (Winn, 1995, 1996, 1997; Taylor, 1996; Osberg, 1997; Dede, 1997) that supports the hypotheses presented for this pilot project. Based on the results of this additional work, further research opportunities are presented in this Addendum.

A.1.1. RESEARCH IN METAPHYSICS, SEMIOTICS AND CONSTRUCTIVISM

The metaphysics of virtual reality are a fascinating subject unto itself (Heim, 1993; Osberg, 1996; Gigliotti, 1996). Certainly, as our philosophical basis for understanding our environment changes, so too will the nature of our perceptions. I find this particularly fascinating when one considers what might be learned from ‘alternate realities’ in which our perceptions, indeed our belief systems may be engaged in ways we can only contemplate at this time.

Regarding the constructivist practice is collaborative learning, we have the opportunity to begin to understand how this technology both draws people together (Rheingold, 1993; McLuhan, 1964), but also separates them (Bowers, 1988, 1992). The research on virtual community development (Rheingold, 1993) appears to indicate that that virtual technologies can go beyond Internet-based chats, MUDs and MUE’s in building viable connections between participants. However, the gap between those that have access and those that do not continues to widen (Negroponte, 1995).

A.2.1. CULTURAL ISSUES

The effect of our cultural beliefs, values and mores have an overarching effect on our behaviors (Brislin, 1993; Shweder, 1991). This becomes clear in many avenues of life, whether we are talking about the perceived need to maintain constant contact with the world through our cellular phones, or participating in the entrenched nature of our cultural rituals, including the rituals of ‘school’ and ‘learning’.

But the very nature of virtual reality challenges us to develop alternative cultures; alternative ways of being that mirror our new experiences (Rheingold, 1995; Laurel, 1990). One does not arise from the other; they simultaneously and continuously forge each other. We must develop a place to integrate our alternative experiences into our knowledge construction process, providing new avenues through which to pursue both ‘teaching’ and ‘learning’.

In this study I was most interested in providing support for individual knowledge construction, as conducted within a specific learning community (Phillips, 1995), and within a given cultural environment (Bruner, 1990). In Bruner’s view, the “folk psychology” of signs, mores, beliefs and behaviors contributes heavily to the manner in which individuals come to create meaning. He states:

> The central concept of a human psychology is *meaning* and processes and transactions involved in the construction of meanings. This conviction is based upon two connected arguments. The first is that to understand man you must understand how his experiences and his acts are shaped by his intentional states, and the second is that the form of these intentional states is realized only through participation in the symbolic systems of the culture. Indeed, the very shape of our lives– the rough and perpetually changing draft of our autobiography that we carry in our minds– is understandable to ourselves and to others only by virtue of those cultural systems of interpretation. But culture is also constitutive of mind. By virtue of this actualization in culture, meaning achieves a form that is public and communal rather than private and autistic. (p. 33)

At Kellogg Middle School, and at all the schools in which we assisted students in designing virtual environments, we discovered children are naturally adaptable to alternative experiences. Their eyes are not yet closed to certain possibilities, nor do they see the world in such concrete terms as many of the adults on our project did. Their conception of the design process incorporated a perspective that my more ‘trained’ approach did not take into account: they wanted to include objects and behaviors that to my way of thinking were inappropriate; for example, a rusted car in the lake, or a chain saw used to change a cow into a hamburger. In the case of the car in the lake, what I saw as an eyesore, i.e. something that ruined *my* aesthetic, was to these students a solid representation of pollution and over-development. When experiencing adverse reactions to students' suggestions, it gave me pause to analyze my own values and beliefs, and to realize how often we overlay students' learning with our own preconceived notions.

A.3.1. MULTI-PARTICIPANT ENVIRONMENTS

Though none of the environments generated during the first two years of the VRRV project were multi-participant, the HIT Lab is currently connecting Children's Hospital and a public school, so that students can collaboratively study global warming (Winn, 1977). There are two ways to connect individuals and schools; either directly or via the Internet. We have not yet begun to tap into the existing power of the Internet, even though alternative technologies are currently being developed.

In the spirit of constructivist learning, it is my hope that we can begin to make better use of this connectivity, especially as we are developing better visualization tools for use (such as VRML) across the Internet as well. I can envision a day when there is a system that connects to, but runs in parallel with the Internet, that will be used for educational purposes alone. Our government is already seeking researchers to define and develop this system. We can expect that virtual reality will be one interface such a system has to offer.

A.4.1. OTHER ISSUES

A.4.1.1. ACCESS

Furthermore, there are issues of access (Negroponte, 1995) and appropriateness (Norman, 1993). Virtual reality is a wonderful tool when used to expand and inform. It should not be used as a reward, a source of social, intellectual or technological demarcation, or as a punishment. The doors are wide open, as this technology is relatively new. However, we are not well known in western society for our egalitarian or philanthropic uses of something that even now is considered relatively ‘elite’ (Osberg, 1994a).

In leaving the software on the computers at the school, we provided the students with a means to create 3-D environments, but we were unable to provide the technology with which to display the children’s 3-D creations stereoscopically. Their creations stayed trapped in 2-D on the screen of the computer.

However, with the advent of less expensive headsets, such as the VR-4 and Crystal Eyes shutter glasses, this too is also changing. The entire world building and experiencing process is coming closer to the desktop every day, instead of remaining a distant dream ensconced in equipment and software well beyond the means of most schools or individual families. A good example of the advances made over the past year is the development of the Ninetendo 64 game machine, which displays 3-D graphics with ease, and provides real-time interaction in a smooth, engaging fashion. Though the user has no control over development and display of content other than that which can be purchased, the retail price of this technology is about $300; a far cry from the $85,000 Division ProVision of the early 1990’s, or the $35,000 version currently in use at the Human Interface Technology Laboratory.

A.4.1.2. TIME

One of the most common complaints that the Kellogg Middle School teachers and students mentioned was the lack of sufficient time and ability to devote enough energy to the project. Subsequent to the Kellogg Middle School project, the VRRV team visited an additional 17 schools in which we conducted world building. In these other environments, teachers and students alike felt like they were continuously trying to ‘catch up’ to where they needed to be in the project.

It is my feeling that this is because in every case the project was seen as an ‘extra-curricular’ activity, rather than as a regular learning practice. One opportunity for further research would be to provide the training and the technology into a classroom environment where it could be used over the course of at least a year. This would provide an opportunity to analyze how the process of world-building could be truly integrated as a meaning-making process in a variety of subjects, and under a variety of circumstances.

By making the process and the technology available for a longer period of time, the effects of the learning curve inherent in any new undertaking would also be minimized. Instead of fighting the battle of trying to teach everything at once; process, design, new software skills, and so on, efforts could be focused instead on outcomes, such as the quality of the environments and of the process that students experienced to create them.

A.4.1.3. TOOLS

Research into developing meaningful virtual tools would be useful (Rose, 1996), as well as designing and testing new navigational paradigms. All of these opportunities involve the use of signs and metaphors to make meaning in a virtual space.

A.4.1.4. PROCESS ISSUES

We faced incredibly tight deadlines on this project. We were constrained in terms of classroom time on task and the calendar as well. The project closed on the day before Thanksgiving break.

There are two issues here: how to make the best educational use of the world-building experience, and how much time to allocate for the process. We had the opportunity to test a variety of process models in subsequent school visits. The VRRV van visited over 70 schools in which over 3000 students got a taste of what virtual reality was all about. In 17 of those environments, we conducted world-building exercises, in elementary, middle and high schools, both public and private. I can attest that the world-building process in particular was a success, but the level of success varied considerably, based on how the project was managed in each school environment.

I would recommend to any school that wants to participate in virtual learning environment development integrate the process into the regular curriculum as much as possible. When it becomes a 'special' project, especially as an after-school project without a clear curricular end goal, it is very difficult to maintain momentum to the end of the development process. This is because it takes a lot of effort on both the teachers and the students part.

I would also recommend that the process be integrated into a special educational theme that runs for at least three weeks. Two weeks are not enough time to really explore and refine all of the ideas which were initially conceived, and in this respect the students at Kellogg were somewhat short-changed, from a Constructivist perspective in which iteration and refinement are an intended part of the process.

If we could have spent three weeks in the classroom at minimum, or perhaps even four, we could have more fully explored design options, and students could have constructed models commensurate with the increased skill that additional time would have bought. However, in subsequent world building projects, we had considerably more time, but less direct teacher/student/classroom involvement. Based on these experiences, the best scenario for classroom-based virtual environment development is one that provides both sufficient project time and *ample* direct interaction with teachers and students.

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APPENDIX A: QUANTITATIVE PRE- AND POST-TEST

APPENDIX B: CONCEPT MAP PRE- AND POST-TEST

APPENDIX C: CONCEPT MAP RATING CRITERIA

CARBON CYCLE

1. Cycle must be visible in the diagram, or described explicitly.
2. The steps in the process need to be evident/labeled/explained.
3. Steps in the Carbon Cycle to be identified: CO_2 formation, O_2 formation, decomposition.
4. Objects needed to complete the cycle: Plants giving off O_2 and taking in CO_2; animals giving off CO_2 and taking in O_2. Release of carbon from the system through decomposing flesh or feces.

ENERGY CYCLE

1. Cycle must be visible in the diagram, or described explicitly.
2. The steps in the process need to be evident/labeled/explained.
3. Steps in the Energy Cycle to be identified: The Food Chain, and how energy transfers from one organism to another, including decomposition and its contribution to plant growth and regeneration.
4. Objects needed to complete the cycle: Blue-green algae, fish, dragon flys, turtle, duck, fox, aligator, birds.

NITROGEN CYCLE

1. Cycle must be visible in the diagram, or described explicitly.
2. The steps in the process need to be evident/labeled/explained.
3. Steps in the Nitrogen Cycle to be identified: Nitrogen fixing, movement of nitrogen through the food chain, denitrofication, decomposition (release of fixed and free nitrogen into the air and soil).
4. Objects needed to complete the cycle: Free nitrogen, lightening storm (cloud with lightening emitting from it), rain transferring fixed nitrogen into the ground for absorption into plants, nitrogen fixing bacteria, plants with fixed nitrogen, duck (to eat plants), fox (to eat duck), dead duck and feces, detnitrofying bacteria.

WATER CYCLE

1. Cycle must be visible in the diagram, or described explicitly.
2. The steps in the process need to be evident/labeled/explained.
3. Steps in the Water Cycle to be identified: cloud formation (condensation), rainfall (precipitation), groundwater accumulation, water vapor (evaporation).
4. Objects needed to complete the cycle: Energy from the sun, water vapor, clouds, rainfall, lake representing groundwater accumulation.

APPENDIX D: SURVEY

APPENDIX E: INTERVIEW LOG SHEET

APPENDIX F: ANOVA TABLES

Table 18 - Objective Test by Group Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	399.48	79	5.06		
PREPOST	493.45	1	493.45	97.58	.000
T1 BY PREPOST	11.88	3	3.96	.78	.507
Total		904.81	83		

Table 19 - Concept Map Analysis by Group

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	166.14	63	2.64		
T1	8.08	3	2.69	1.02	.389
Total		174.19	66		

Table 20 - Concept Map Pre-Post Score by Group Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	60.36	63	.96		
PREPOST	68.75	1	68.75	71.75	.000
T1 BY PREPOST	2.12	3	.71	.74	.533
Total		131.23	67		

Table 21 - Concept Map Analysis by Built vs. Chosen World by Group

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	66.84	63	1.06		
BUILT	2.16	1	2.16	2.04	.158
T1 BY BUILT	49.53	3	16.51	15.56	.000
Total		118.53	67		

Table 22 - Concept Map Analysis by Pre- and Post-test Scores by Built vs. Chosen World by Group (T1)

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	50.07	63	.79		
PREPOST BY BUILT	8.32	1	8.32	10.47	.002
T1 BY PREPOST BY BUILT	14.54	3	4.85	6.10	.007
Total		72.93	67		

Table 23 - Concept Map Constructivist vs. Traditional Pre- and Post-test Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	32.48	42	.77		
PREPOST	45.02	1	45.02	58.23	.000
Total	77.50	43			

Table 24 - Concept Map Constructivist vs. Traditional Built vs. Chosen Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	81.48	42	1.94		
BUILT	.02	1	.02	.01	.913
Total	81.50	43			

Table 25 - Concept Map Constructivist vs. Traditional Pre- and Post-test by Built vs. Chosen Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	38.13	42	.91		
PREPOST BY BUILT	.37	1	.37	.41	.526
Total	38.50	43			

Table 26 - Concept Map Constructivist vs. No Instruction Pre- and Post-test Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	30.00	23	1.30		
PREPOST	24.00	1	24.00	18.40	.000
Total	54.00	24			

Table 27 - Concept Map Constructivist vs. No Instruction Built vs. Chosen Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	34.33	23	1.49		
BUILT	.67	1	.67	.45	.511
Total	35.00	24			

Table 28 - Concept Map Constructivist vs. No Instruction Pre- and Post-test, Built vs. Chosen Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	18.96	23	.82		
PREPOST BY BUILT	15.04	1	15.04	18.25	.000
Total	34.00	24			

Table 29 - Concept Map Constructivist vs. No Instruction Mean Scores Analysis

Mean Scores

Constructivist vs. No Instruct.	Pre-test	Post-test	t-tailed Sig
Constructivist (*n* = 24)	1.28(.843)	3.12(.927)	.000
No Instruction (*n* = 24)	2.25(1.29)	2.46(1.38)	.558

Note: Standard deviations in parentheses.

Table 30 - Concept Map Traditional vs. No Instruction Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	126.21	65	1.94		
TREAT	.12	1	.12	.06	.807
Total	126.33	66			

Table 31 - Concept Map Traditional vs. No Instruction by Pre- and Post-test Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	98.87	65	1.52		
PREPOST	8.14	1	8.14	5.35	.024
TREAT BY PREPOST	6.08	1	6.08	4.00	.050
Total	113.09	67			

Table 32 - Concept Map Traditional vs. No Instruction Mean Scores Analysis

Mean Scores

Traditional vs. No Instruction	Pre-test	Post-test	t-tailed Sig
Traditional (*n* = 43)	1.74(1.56)	2.67(1.34)	.000
No Instruction (*n* = 24)	2.25(1.29)	2.46(1.38)	.558

Note: Standard deviations in parentheses.

Table 33 - Interview Data by Group (T1)
Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	133.00	65	2.05		
T1	17.10	3	5.70	2.79	.048
Total		150.10	68		

Table 34 - Interview Data by Built-Experienced
and Group (T1) Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	37.13	65	.57		
BUILT/EXP	8.38	1	8.38	14.68	.000
T1	7.49	3	2.50	4.37	.007
Total		53.00	69		

Table 35 - Concept Map Data by VR vs. No VR
Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	166.00	65	2.55		
VR1	8.22	1	8.22	3.22	.077
Total	174.22	66			

Table 36 - Concept Map Data by Pre-Post and
VR vs. No VR Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	62.36	65	.96		
PREPOST	51.88	1	51.88	54.08	.000
VR1 BY PREPOST	.12	1	.12	.13	.722
Total	114.36	67			

Table 37 - Concept Map Data by Built-Chosen by VR vs. No VR Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	116.26	65	1.79		
BUILT	.23	1	.23	.13	.722
VR1 BY BUILT	.11	1	.11	.06	.806
Total	116.60	67			

Table 38 - Objective Test Data by VR vs. No VR Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	1053.01	81	13.00		
VR1	20.03	1	20.03	1.54	.218
Total	174.22	66			

Table 39 - Objective Test Data by Pre-Post by VR vs. No VR Analysis of Variance

SOURCE	SS	DF	MS	F	*p*
WITHIN+RESIDUAL	409.58	81	5.06		
PREPOST	395.13	1	395.13	78.14	.000
VR1 BY PREPOST	1.78	1	1.78	.35	.554
Total	806.49	83			

VITA

Educational Environment
Research and Development

Strategic
Market Development

Market/Product/Business
Management

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Qualifications and Accomplishments:

- Managing Principal in a leading-edge virtual environment software development startup that has been profitable since inception
- Managed a large-scale ($1.5M) educational environment research and development project, delivering virtual reality educational environments to a multi-state student/teacher base
- Author of ‘Dynamic Planning for the High Technology Business’,and ‘Virtual Environment Design: A Primer’
- Experienced in building client base and market share for technology, business and environmental consulting companies
- Developed a new consulting department within the Ernst & Whinney Information Technology group, including marketing, operations and human resources plans, and established an initial client base

Areas of Expertise:

- Business and Project Management
- Strategic Analysis
- Marketing/Sales Management
- Virtual Environment Design
- Educational Assessment
- Multi-media Authoring

- Organizational Change Management
- Leadership and Team Building
- Strategic Partner Development
- Business & Technical Writing
- Advertising/Public Relations
- Systems Design
- Graphic Design
- Education/Training Programs

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Education:

Degrees Granted:

MBA - Organizational Management/Marketing; Seattle University, 1988
BSDP - Management Information Systems; Griffin College, 1982
BAHE - Interior Design/Graphic Art; Washington State, 1981

Current Coursework:

Ph.D - Education Communication and Technology; University of Washington, 1997.

Management/Business/Academic Experience:

FIRSTHAND LLC; Seattle, WA; 1993 - Current.
PRINCIPAL - Perceptual and Educational Technologies Research and Development

Primary responsibilities as the business manager for this limited liability company include business and market development, strategic alliance development, project management, public relations, and technical assistance in concept development and virtual environment design and programming. The company provides four services: research and development of interactive educational and entertainment environments that utilize multiple perceptual channels to enhance the participants' experience, 3-D Training and Development seminars, 3-D and 2-D Consulting Services, and HTML/VRML WWW Development services. The company maintains a strong liaison with the Human Interface Technologies Laboratory, described below.

HUMAN INTERFACE TECHNOLOGY (HIT) LABORATORY, UNIVERSITY OF WASHINGTON; Seattle, WA, 1992 - 1995.
RESEARCH ASSOCIATE AND PROJECT MANAGER - Educational Technology Research and Development.

Responsible for the development of marketing and business plans, marketing strategy, organizational development, and constituent relations. Research and development of strategic partner relationships with industry and governmental agencies. Maintenance of deadline-driven schedule of lab-school interaction, including initial contact through research and analysis process. Design and development of virtual and multi-media educational environments, assessment tools, research designs, and reporting mechanisms, and conveyance of findings resulting from research, including presentation development and delivery, public speaking engagements, and academic and industry publications. HIT Lab representative at academic conference, government and industry functions. Active participant in the international ACCESS Foundation distance learning World-Wide-Web network of administrators and educators, and other national and international Internet-based educational technology bulletin boards and listservs.

Management/Business/Academic Experience (continued):

PENTEC ENVIRONMENTAL, INC./PENTEC TECHNOLOGIES, INC.; Edmonds, WA; 1990 - 1991
DIRECTOR, STRATEGIC MARKET DEVELOPMENT - Biological Technologies Research and Development, **DIRECTOR, CORPORATE DEVELOPMENT** - Biological and Environmental Consultants (Northwest Practice)

Responsible for the development of marketing and business plans, marketing strategy, organizational development, and client relations. Provided direct assistance and advice to the president, and was a full voting member of the Board of Directors. Researched domestic and international joint venture and strategic alliance alternatives for manufacturing biological research systems. Developed a networked client information system to track dynamic client and market information. Established infrastructure relationships with high-technology attorneys, business consultants, and financiers.

KPMG PEAT MARWICK; Seattle, WA; 1989 - 1990
SENIOR CONSULTANT - Management Consulting group (Worldwide)

Authored and edited several major documents for the partnership, including a national training course entitled "Strategic Planning for High Growth Companies", and a client guidebook entitled "Dynamic Planning for the High Technology Business." Provided strategic planning, business review, and organizational development consulting services for a variety of clients, including manufacturers, retail concerns, and the high technology industry.

MANAGEMENT CONCEPTS; Seattle, WA; 1987 - Current
PRINCIPAL - Management Consultants (Northwest practice)
Developed marketing concept and implementation plans for a variety of clients, including software and hardware firms. Also responsible for the development of technical manuals and software

documentation. Assisted in product introduction of a database-driven desktop publishing system in Q1 1990.

SEATTLE UNIVERSITY, Albers School of Business and Economics; Seattle, WA; 1985 - 1988

ADJUNCT FACULTY/RESEARCH ASSISTANT - Private University

Responsible for the development and delivery of course curriculum in Marketing and Management Information Systems. Also a former MBA Alumni Executive Board Member from 1990-92, and a regular guest speaker at the University. Active in undergraduate student development issues, such as mentorship and career development strategies.

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Management/Business/Academic Experience (continued):

ERNST & WHINNEY; Seattle, WA; 1986 - 1987
CONSULTANT - Management Consultants (Worldwide)

Started a Microcomputer Consulting group within the Information Technology group, to service existing and new clients' Management Information decision and implementation needs, using Computer hardware companies, and the audit, tax and POEB (Privately Owned and Emerging Business) staff to cross-sell services.

SEA GALLEY STORES/FLAKEY JAKES; Seattle, WA; 1983 - 1986
SYSTEMS ANALYST/MIS MANAGER - National restaurant chain.

Provided first rendition systems design and programming for a multiplicity of accounting and restaurant applications, including intercompany MIS reporting systems.

Associations:

New Horizons for Learning Education and Technology Task Force
IEEE Computer Graphics Division
IICS
911 Digital Media Group
ACCESS Foundation

Community Activities:

New Horizons for Learning Executive Committee Board Member; 1995 - Present

Dream a Dolphin Foundation: Research Board Member; 1995 - Present

Educational Systems Incorporated (ESI): Advisory Board Member; 1995 - Present

Source Child Center, Mountlake Terrace, WA; 1992-95 Board President

PSC Creative Technology Camp VR Co-teacher; 1992

Everett Community College; Judge for the Washington State
Technologies Conference for High School Students - Physics of
Musical Instrument Design Competition; 1991

MBA Alumni Association, Seattle University Executive Board; 1984-87

Kimberley M. Osberg

Partial Publication List:

The Effects of Technology in the Workplace: A Study of Six Industries
University of Stockholm School of Economics, May 1987

Strategic Planning for High Growth Companies
KPMG Peat Marwick, September 1989

Dynamic Planning for the High Technology Business
KPMG Peat Marwick, High Technology Guidebook Series, September 1990

Strategic Planning for the 21st Century
Seattle University Course Materials, January 1990

Mergers and Acquisitions; Mesh or Mess?
Seattle Business Journal, February 1990

dSIGN, The Retail Signage System (Software Users Reference, and Getting Started Manual)
ACCESS, a communications company, May 1990

Virtual Reality and Education: A Look at Both Sides of the Sword, Human Interface Technology Lab Technical Report, April 1993.

Puzzle World: A Spatial Cognition Learning Environment, Human Interface Technology Lab Technical Report, September, 1993.

Virtual Education: Is it Real Enough? A Moral Analysis, Education Leadership and Policy Paper Series, University of Washington, December, 1993.

Rethinking Educational Technology: A Postmodern View, Human Interface Technology Lab Technical Report, September, 1994.

Virtual Reality and Distance Learning: Possibilities and Pitfalls, Human Interface Technology Lab Technical Report, October, 1994. Presented at the Computer Managed Learning Conference, December 4-6, 1994, Melbourne, Australia.

A Teacher's Guide to Developing Virtual Environments, Human Interface Technology Lab Technical Report, March, 1995.

Semiotics and the Design of Objects, Actions and Interactions in Virtual Environments (with Winn, W. and Hoffman, H.), Presentation paper at the American Educational Research Association annual meeting, April 18-22 1995, San Francisco.

The Role of Mental Imagery in Meaning Making: A Semiotic View, Human Interface Technology Lab Technical Report, April, 1995.

Virtual Environment Design: A Primer (1996) Web-based education tool distributed by Hewlett-Packard Corporation, Colorado Springs, CO.

But What's Behind Door Number 4? Virtual Reality and Ethics: A Discussion. Proceedings of the First International Conference on Virtual Reality and Ethics, University of Michigan, Ann Arbor, MI, October 4 - 6, 1996.

The Effect of Having Grade Seven Students Construct Virtual Environments on their Comprehension of Science. Paper presented at the 1997 AERA Conference, March 24-28, Chicago, IL.

The Effect of Student Construction of Virtual Environments on the Performance of High- and Low-ability Students. With Winn, W. and others) Paper presented at the 1997 AERA Conference, March 24-28, Chicago, IL.

GLOSSARY

Artificial Reality. Introduced by Myron Krueger, a computer scientist, in the 1970s to describe his computer-generated responsive environments. Krueger developed the basis for projected VR systems, such as the ***CAVE***. (M. Krueger, Artificial Reality, 1992) (See ***Virtual Reality*** and ***Cyberspace***)

Augmented Reality. Projecting data and virtual objects onto transparent glasses. Overlaying and intermixing the virtual and the real worlds. An example of an augmented reality application would be a surgeon in the operating room seeing X-ray and other data projected inside his glasses, while he is also able to view the real operating room.

Behaviors. The actions ascribed to virtual objects in a virtual environment.

Billboarding. A technique to increase the visual complexity and realism of a virtual environment using complex texture maps displayed on a flat plane, similar to a billboard sign. The trick of this technique is to swivel the front of the billboard so that it is always facing the participant. Billboarding is one way to make realistic looking worlds with low numbers of ***polygons***.

Bitmap. A 2-D graphic image made up of dots, also called pixels.

Boom. A 3-D display suspended and counterbalanced by a weighted boom. A boom can track the user's motion in real-time, and can offer high resolution image display because there is no weight resting on the user's head. A boom can either attach to the user's head like an ***HMD*** or be like binoculars where the user steps up and peers inside.

Cartesian Space. A three dimensional coordinate system developed by Rene Descartes to plot objects along three, graduated axes: ***X, Y, and Z***.

CAVE (Cave Automatic Virtual Environment). A CAVE is an enclosed room fitted with projection displays. A CAVE allows a number of participants to experience the same virtual environment and experience a feeling of group immersion.

Center point. A unique point in the geometry of a virtual object. The center point may or may not be located at the geometric center of an object, but it is the point which the virtual reality authoring software conventionally uses to define the location of a virtual object in a world.

Concept Mapping. Concept mapping is a process where individuals organize a domain of knowledge for themselves and express their understanding of the various inter-relationships in the form of a diagram (Novak & Gowin, 1984).

Constraining. A technique which limits the motion of a virtual object in either ***Cartesian space*** or in ***orientation***. An example of a constrained virtual object is a door, which must be constrained to only swing open and closed along a single, vertical axis.

CPU. Central Processing Unit. The main "brain" of a microcomputer.

Cyberspace. 1. A place filled with virtual objects populated by people with virtual bodies. A special kind of virtual space which promotes experiences involving the whole body. (Walser, 1991). 2. A term coined by William Gibson in his book Neuromancer (Gibson, 1992) to describe a shared virtual universe operating within the sum total of all the world's computer networks. (See ***Artificial Reality*** and ***Virtual Reality***). A virtual space, occupied by one or more human or artificial beings, created and maintained by computers and other machinery.

Dataglove. One type of ***input device***. A glove wired with sensors to track and detect motion of the hand; translates hand gestures into meaningful interactions in a virtual environment, such as picking up or dropping virtual objects. Datagloves can be fitted to give ***tactile feedback***, causing the user's hand to feel pressure in response to grasping a virtual object.

Degrees of freedom (DOF). There are six degrees of motion in three dimensional space: up-down, left-right, front-back (x, y, z in ***Cartesian space***) and ***yaw, pitch, roll*** (three degrees of ***orientation***). A ***standard computer mouse*** has 2DOF along the x and y axis. A ***flying mouse***, able to move in all dimensions of has 3-D space, is said to have 6DOF.

Field of View (FOV). The whole of what we are able to see with our two eyes. FOV is measured as an angle in degrees. The normal computer display at an average viewing distance of 30 inches subtends an angle of about 5 degrees. Large screen displays cover an angle of 20 to 30 degrees. Most HMD's offer from 40 to 100 degrees FOV.

Fish Tank VR. A computer monitor fitted with a stereographic display device that lets the viewer peer into a 3-D virtual space, as if looking into a fish tank. Fish tank systems can be fitted with head tracking which improves the feeling of immersion.

Flat Shading. The simplest form of shading, where a single value of color is applied to each face of a polygon, as opposed to ***Phong Shading***.

Force Feedback (FFB). Force feedback devices simulate the sensation of weight or resistance in the virtual environment. FFB devices produce a variable force on the body, or on a tool which the user manipulates such as a pencil, increasing the feeling of immersion in the virtual world. (see ***Tactile Feedback***).

Frame Rate. The major consideration of a graphic renderer for VR applications is the frame generation rate. It is necessary to create a new frame every 1/20 of a second or faster. 20 frames per second (fps) is roughly the minimum rate at which the human brain will merge a stream of still images and perceive a smooth animation. 24 fps is the standard rate fore limb, 25 fps is PAL TV, 30 fps is NTSC TV. 60 fps is Showscan film rate. This requirement eliminates a number of rendering techniques such as ray tracing and radiosity. These techniques can generate very realistic images but often take hours to generate single frames.

Freeware VR Programs. There are a number of free programs available to create and render virtual environments. This software is generally copyrighted freeware, which means that the original authors retain the copyright to commercial use, but distribute the software free to interested users. Most of these programs are not as highly polished as commercial software, and support can often be totally lacking for the would-be developer. But all things considered, freeware can be an excellent first entrance into the world of virtual reality.

Geometry. The description of an object in terms of its dimensions

Graphics Accelerators. Specialized hardware to increase speed of graphics manipulation.

Haptic Displays/Interfaces. Devices that use all the physical sensors that provide us with a sense of touch at the skin level and force feedback information from our muscles and joints.

Hierarchical Structure. Within a virtual environment, objects that have relationship to other objects are described within a hierarchy. The ‘world’ is the highest level in the hierarchy, often followed by different ‘rooms’ or ‘sections’ of the ‘world’, followed by the objects associated with that section, and so on. This structure defines what are called ‘parent-child’ relationships, with the ‘parent’ object higher within the hierarchy than the child object.

HMD (Head Mounted Display). 1. A set of goggles or a helmet with tiny monitors in front of each eye that generate images, seen by the wearer as being 3-D. VPL Research refers to the HMD’s they sell as Eyephones. 2. A device, which is fastened to the head, and used to display a computer-generated scene. A Head Mounted Display typically provides a stereo-optic (3D) view through the use of two LCD or small CRT displays. Brand names include EyePhone (VPL Research), Visette (W-Industries), Private Eye (Reflection Technologies) and others.

Hypermedia. A form of media in which information is linked to other related information, in which the user has control over the dynamic movement from link to link. This kind of media presents design challenges in attempting to provide relevant links that make sense to the user. World Wide Web browsers are an excellent example of hypermedia in practice.

Immersion; Immersive. The user feels as if he or she is 'placed' within the environment. This feeling is often referred to as ***presence.*** This feeling of presence is generated and enhanced in two ways: 1) using a stereoscopic viewing device; 2) having a wide field of view. The feeling of presence, of "being there", surrounded by space and capable of interacting with all available objects is one of the hallmarks of good VR.

Input Device. A device used to communicate with and control the user's actions within a virtual (or non-virtual) environment. Most virtual input devices, such as a ***dataglove*** or ***flying mouse*** are externally 'tracked' for their location in ***Cartesian space***, relative to the Cartesian coordinates of the virtual environment. It is through this device that the computer can interpret relative spatial relationships of the user and objects in the environment, providing the user with an added sense of ***presence*** as he or she navigates within the environment.

Interaction; Interactive. Interaction implies that the participant or user is engaged with the system, usually in more than just a perceptual or cognitive sense. Interaction is often defined at the system level, in that the system will not function without input from the participant. In the virtual environment, the user should be able to interact with objects and other participants, hopefully by natural movements, gestures or words. For example: users can physically extend their hand and grasp a virtual object using a dataglove, open and close doors as one would in the real world, or move freely through a virtual rendition of an architectural space.

Interactions. Interactions are those behaviors that occur between participant and environment, participant and object, or object to object. They are often cause-and-effect driven, though they can certainly be programmed to be much more arbitrary. Interactions are what make virtual environments interesting.

Lag. Delay between an action and its visual, acoustic, or other sensory feedback, often because of inherent delays in the tracking devices, or in the computation of the scene.

LBE (location based entertainment). A VR game that involves a scenario based on another time and place; filling a studio or space with VR games.

LCD (Liquid Crystal Display). Display devices that use bipolar films sandwiched between thin panes of glass. They are lightweight and transmissive or reflective, and ideal for HMD.

Lighting. Lighting is used in a virtual environment to enhance and focus one's attention in much the same way that lighting is used in theater. There are different kinds of lighting (and shading) that can also be applied directly to objects, which can drastically change their appearance. (See ***phong shading***).

LOD (Level of Detail). A model of a particular resolution among a series of models of the same object. Multiple LOD's are used to increase graphics performance by drawing simpler geometry when the object occupies fewer pixels on the screen. LOD selection can also be driven by graphics load, area-of-interest, gaze direction, and the relative distance of the participant from an object. Normally, the further a participant is from an object, less detail is required.

Mental Models. Mental models are the conceptual representations that humans (and perhaps other organisms create to give meaning to their experiences and knowledge. Metal models can be likened to large hierarchical and relational networks, whereby information is taken from the environment, and meaning is constructed in a manner that makes sense to the individual.

MOO - An **o**bject-**o**riented ***MUD***.

Motion Parallax. Objects at different distance and fixation points move different amounts when the viewpoint is dollied along the x axis (left- right).

MUD. A **m**ulti**u**ser **d**ungeon; a place on the Internet where people can meet and browse (some of which are also a ***MOO***).

Multimedia. Typically, a presentation blending of text, graphics, audio and video from various sources. May be computer augmented and/or controlled. A sub-set of ***Hypermedia***.

Orientation. The orientation of a user (or an object) is how that user or object is aligned in Cartesian space. If the participant's view is skewed off the normal (parallel) angle of the horizon, it will contribute to a sense of disorientation, as our ***proprioceptive*** and ***vestibular*** systems seek this normal angle of orientation.

Parallel Processors. Virtual reality, and other graphics-intensive presentations require very heavy processor power. Some developers have gone to linking processors together, so that they run in parallel, providing substantial additional power.

PC. Personal computer.

Phong Shading. A method for calculating the brightness of a surface pixel by linearly interpolating points on a polygon and using the cosine of the viewing angle. Produces realistic shading.

Photorealism. An attempt to create realistic appearing images using level of detail, color and texture to fool the eye.

Pitch. The angular displacement of a view along the lateral axis.

Pod. Capsule or cabin designed to hold one or more players in a VR-based game. Typically a pod includes connections for I/O devices such as ***HMD's***, headphones, joysticks, etc.

Polygon Mesh. A polygonal object where, for each object in a mesh, there is a common pool of points that are referenced by the polygons for that object. Transforming these shared points reduces the calculations needed to render the object. A point at the edge of a cube is only processed once, rather once for each of the three edge/polygons that reference it.

Polygons. Polygons are an ordered set of vertices connected by sides. These can be dynamically created and texture-mapped using various sources of image data. Various hardware platforms support different texturing methods and quantities. Rendering is performed in either wireframe, smooth-shaded or textured modes.

Presence; Telepresence. One of the defining characteristic of a good VR system, a feeling of being there, immersed in the environment, able to interact with other objects there.

Projected Reality. A VR system that uses projection screens rather than ***HMD's*** or personal display monitors.

Proprioceptive System. Humans (and other organisms) have the capability to accurately judge where their bodies are in Cartesian space. For example, even though I may have my hand behind my back, I still know where it is located relative to the rest of my body and to the environment.

Real-time. A phrase used to describe computer graphics and interactions that appear to the user without lag or flicker (e.g. 60 cycles per second (cps) displays; highly ***interactive*** computation). Real-time graphics and interactions contribute to the participant's sense of ***presence***, in that the brain is not forced to wait for feedback from the system once an action or interaction has been initiated.

Render. The process of drawing a graphics object as pixels on a computer display.

Resolution. Usually the number of lines or pixels in a display, e.g. a VGA display has 640 by 480 pixels per screen.

Roll. The angular displacement of a view along the longitudinal axis.

Scaling. In the virtual environment, objects can be manipulated along any axis relative to each other, and relative to the user. This process allows the designer to change both the size and the relative dimensions of an object. In addition, the environment itself can also be changed in the same fashion, using multiplication or division, providing the user with the opportunity to 'go inside' microscopic organisms, or to manipulate 'the universe' with his or her hand. Using scale effectively is one of the most powerful aspects of virtual reality as it can change the participant's perspective in a dramatic manner.

Sensors. Sensors are used in the virtual environment to react to changes in either the state of the participant, or objects in the virtual environment, or in response to multiple devices connected to lights, objects, viewpoints, etc., in the real world.

Shutter Glasses. LCD screens or physically rotating shutters used to see stereoscopically when linked to the frame rate of a monitor.

Simnet. A prototype networked simulation system built by BBN for training military skills in tanks, helicopters, and other vehicles. Using networked graphics and displays built into physical mock-ups, it has been called a vehicle-based VR or synthetic environment.

Simulator Sickness. The disturbances produced by simulators, ranging in degree from a feeling of unpleasantness, disorientation, and headaches to nausea and vomiting. Many factors may be involved, including sensory distortions such as abnormal movement of arms and heads because of the weight of equipment; long delays or lags in feedback, and missing visual cues from convergence and accommodation. Simulator sickness rarely occurs with displays less than 60 degrees visual angle.

Spatialized Sound. In a virtual environment, or even in a well-designed theater, sound cues can be programmed to 'move' through space in the way that our human ears can interpret as actual motion. The change in the qualities of sound are what provide our brains with data that can be interpreted for distance and direction. Spatialized sound is a solid perceptual cue that can add a great deal of realism (and information for the user) to an environment.

Stereoscopic Viewing Device. A stereoscopic viewing device allows the participant to 'see' a slightly different view of an environment, just as our eyes do in the real world. Our brain recomposes the two images, giving the viewer a sense of depth, thereby adding the 3-D element to the experience. It can be a problem if the views presented to each eye are either too close together, or too far apart. This can be extremely disorienting for the viewer.

Synthetic Environments. VR displays used for simulation.

Tactile Displays. Devices like force feedback gloves, buzzers, and exoskeletons that provide tactile, kinesthetic, and joint sensations.

Tactile Feedback (TFB). Sensation applied to the skin, typically in response to contact or other actions in a virtual world. (Compare to ***Force Feedback***.) Tactile Feedback can be used to produce a symbol, like Braille, or simply a sensation that indicates some condition.

Tactile Stimulation. Devices that can provide feedback to the user regarding haptic interactions. Examples include force feedback gloves, buzzers, and exoskeletons that provide tactile, kinesthetic, and joint sensations.

Telepresence. The ability to act and interact in a distant environment through cybernetic technology. The electronic analog to an out-of-body experience.

Texture Animation. The process of requesting that a texture be re-applied to a surface at a certain rate, giving the user the sensation that the texture is actually 'moving'. This is a particularly useful technique for adding realism to objects who's' surfaces generally *do* move, such as water.

Texture Mapping. A bitmap added to an object to give added realism.

Three Dimensional (3D) Computer Environment. See ***Virtual Reality***.

Tracker. A device that emits numeric coordinates that describe its changing position in Cartesian space. Typically, position trackers are attached to head mounted displays (see above) and to input gloves. Position trackers work via various technologies, including direct connection, magnetic sensing, acoustic or optical tracking. Manufacturers include Ascension Technology, Logitech, Polhemus, Shooting Star Technology, and others.

Vestibular System. Humans (and other organisms) have a complex system of inner-ear canals and very small bony structures which reflect our angle of orientation relative to the environment. Normally, it is the vestibular system that keeps our bodies upright in space, unless we choose otherwise. Individuals with vertigo have problems with their vestibular systems. Note, in a virtual environment, orientation is completely arbitrary, which can be confusing to the vestibular system, resulting in disorientation and ***Simulator Sickness***.

Virtual Environments (VE). Realistic simulations of interactive scenes. See ***Virtual Reality***.

Virtual Object. An object which is not physically tangible, but is perceptually tangible nonetheless. Holograms and objects found in virtual environments are two examples.

Virtual Prototyping. The use of VR for design and evaluation of new models.

Virtual Reality (VR), Virtual Environment (VE). 1. That sense of place and being which exists in cyberspace. Artificial Reality implies non-immersion technology, such as Myron KreugerÕs Video Place. Virtual Reality commonly implies full-immersion technologies using goggles and similar devices. Virtual Environment and Synthetic Environment are terms typically used by the US Defense Department and Space Agency and carrying the same essential meaning. See also ***Artificial Reality (AR), Synthetic Environment (SE).*** 2. An immersive, interactive simulation of realistic or imaginary environments.

Virtual World. Referencing the entire virtual environment or universe.

Visual Realism. See ***photorealism.***.

Visualization. Use of computer graphics to make visible numeric or other quantifiable relationships.

Workstation. Personal computing system optimized for high performance. Typically workstations include high performance, high resolution graphics display systems, and use the UNIX operating system. Workstations are typically considered to be more powerful than PCs, but that difference is fading quickly.

X, Y, and Z axes. The designated planes of origin, by which all locations in Cartesian space are designated. In the real world, Y represents height, X represents width, and Z represents depth. Depending upon the virtual system being used, these coordinate references may change.

Yaw. The angular displacement of a view around the vertical axis.