Spatial Cognition in the Virtual Environment

Kimberley M. Osberg
College of Education
University of Washington

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Abstract
Spatial processing skills are an important component in cognitive development. It has been shown that there are many students who, because of their perceptual differences could use assistance in developing spatial concepts and relationships through experience in multi-perceptual alternative learning environments. Virtual reality has potential as a setting for multi-perceptual, experiential learning. This study evaluates the effect of designing and experiencing a virtual world as a spatial processing skill enhancement method, and as an aid to cognitive development. A group of ten 12-14 year-old, neurologically impaired children took part in an intensive, week-long virtual reality class at the end of their regular summer school program. These children were selected because all had difficulty in spatial processing that effected their academic performance as well as their day-to-day lives. All were pre-tested for spatial processing ability using the Inventory of Piaget’s Developmental Tasks (IPDT). During the class, 3-D design software was used to develop "puzzle pieces", that were combined into a cohesive whole at the end of the week. The resulting "Puzzle World" was experienced by each of the children at the conclusion of the class, after which eight of the ten were again tested on the IPDT. In addition to the post-test, personal interviews were conducted. A two-tailed t test indicates that the effect of the week-long course was significant, \( t = 5.16, df = 7, p < .001 \). Mean scores improved for the group, from a pre-test mean of (\( M = 45.00 \)), to a post-test mean of (\( M = 49.75 \)). These results were consistent with the hypothesis that an intensive 3-D processing class culminating in a virtual experience can enhance spatial processing skills. The intensive training may have encouraged these children to contemplate spatial issues in a manner not previously experienced, and may have created deeper spatial understanding through the opportunity to directly manipulate objects and navigate through a 3-D environment. This deeper understanding might have contributed to the higher test scores.

Introduction
Cognition is a complex process that is predicated on the interaction of an individuals' sensory-motor and neurological systems. Spatial cognition is an important building block to general cognition, as it is the process by which a child perceives, stores, recalls, creates, edits, and communicates about spatial images. The process of spatial cognition allows a child to create meaning by manipulating images of the world in which (s)he exists, and those that originate in their own mind. If a child has difficulty with spatial cognition, it is likely that (s)he will have difficulty
in the academic environment and possibly in daily life as well. Therefore, it is important to understand how spatial cognition can be habilitated and sustained.

Ability and performance in spatial cognition is dependent upon the development of seven underlying levels of neurological support, as presented in Figure 1.

LEVEL VIII. Visual/Spatial Integration
Auditory/Visual Integration

LEVEL VII. Binocularity
Auditory/Linguistic Integration
Auditory Sequencing

LEVEL VI. Laterality

LEVEL V. Ocular Motility
Visual/Motor Integration

LEVEL IV. Proprioception

LEVEL III. Kinesthesia
Muscle Tone

LEVEL II. Vestibular Functions

LEVEL I. Tactility
Olfaction
Gustation

Figure 1, Levels of Neurological Support for Spatial Cognition (from HANDLE, Rabinovitch, 1992)

As can be seen from the chart, visual/spatial integration and auditory/visual integration are the culmination of perceptual development. In Piaget's model, these skills would begin to appear during the concrete operations stage (ages 7-11), and would continue to develop through the formal operations stage (ages 12-16 and beyond).

In the classroom, a child needs to actively attend both visually and aurally, both components of spatial cognition. Visual and aural systems rely on a child's vestibular, proprioceptive, and kinesthetic senses to be active and functioning, yet "running in the background". It is also important that the child be able to minimize attention devoted to tactile and olfactory senses, so that one's focus can be maintained in the visual and aural arenas. This is difficult for many children.

This exploratory study examined the effect of intensive training in three-dimensional design culminating in a visit to a virtual world as a habilitative process for enhancing certain spatial processing skills of a group of neurologically impaired children (ages 11-14), in the interest of enhancing both their academic performance and their day-to-day lives. Specifically, we were interested in the child's abilities in spatial relations, sequencing, classification, transformation and rotation, whole-to-part relationships, visualization, and creative problem-solving.

Spatial relations is defined as an understanding about the relationship between objects in space, both in dynamic and static environments. Sequencing has to do with the order of both objects and events. It is conservation of order, even when the orientation of an object or set of objects changes. Classification is the ability to comprehend relationships between objects and to develop meaningful groupings. It is a means of developing mental order. Transformation is the ability to mentally rotate objects in space, and be able to maintain orientation and attributes during that transition. Whole-to-part relationships are needed to construct and deconstruct complex objects, developing an understanding at both
the micro and macro level. Visualization is the ability to construct, manipulate and interpret images in the mind. Creative problem solving is the external manifestation of all of the above activities coupled with reason.

Selecting a Design Goal

In designing an effective spatial processing environment, our goal was to provide children with a means to develop spatial problem solving skills that will contribute to their spatial cognition, while providing an engaging and interactive atmosphere in which to work both individually and as a group. As this was a special population, we felt it best to take a very systematic approach to determining exactly how best to accomplish the goal of enhancing a child’s spatial cognition.

Spatial Processing Skill Development

The stage theory of childhood development as described by Piaget (1952) has a great deal of relevance when one discusses mental maturity for certain types of reasoning, specifically higher level thinking skills. Regardless of the order or the age at which these skills appear, Piaget was able to identify important components to spatial processing, such as the ability to comprehend perspective, transformations, ordinal relations, classification, kinetic imagery, reciprocity, transitivity, probability, and conservation (Patterson & Milakofsky, 1980).

Howard Gardner (1993) is also a strong advocate of “spatial intelligence”, and its relationship to other intelligences and cognition. In Gardner’s view, spatial ability and spatial cognition are the basic building blocks that a child needs in order to develop higher level thinking skills, specifically those that complement verbal processing skills. As we move closer towards being an “intellectual” rather than an “enactive” (Bruner, 1966) learning society, the opportunity and necessity for practice in the spatial realm has been minimized. However, fully half of the population, when tested, indicates a preference for visual rather than verbal learning style. (Kirby et al, 1988) Learning style preference has been given little attention with regard to curriculum or assessment development. Gardner’s answer is to re-integrate development of all of the intelligences that he has identified back into the curriculum, in appreciation of a holistic approach to both individuals and the education process. One’s learning style preference as a basis for spatial cognition is discussed in greater detail with regard to future research in the Discussion section.

Pelligrino et al (1984) has separated “spatial ability” into two components; spatial relations and spatial visualization. His study focused on psychometric measurement of speed, power, and complexity of individuals’ spatial manipulations. Sternberg (1990) states that regardless to which intelligence theory one accepts, it is generally agreed that the ability to think quickly, and to manipulate complex mental models are both signs of intelligence. Rabinovitch (1992) also points out the importance of developing one’s spatial cognitive abilities in the interest of language acquisition, mathematical comprehension, and as an important underpinning for learning. Similar results have been cited by Witkin (1977), Cohen (1985), and Anllo-Vento (1992).

The Visual Component

But spatial cognition is not simply a visual process; it is a multifaceted, multi-perceptual sequence of events. Wiley (1990), though focusing primarily on the visual component, has developed a relatively broad model of spatial cognition. He has developed a “Hierarchy of Visual Learning” model, which provides a structural framework for how one learns through the process of “visual cognition, visual production, and visual resolve.” These stages are dependent upon one and other, and represent one’s ability to mentally comprehend, store, retrieve, create, edit, and communicate spatial information. Figure 2 illustrates the primary stages of visual learning, and Figure 3 the hierarchical stages of visual learning.

(Not Available)

Figure 2, Primary Stages of Visual Learning within the Hierarchy of Visual Learning
In essence, what Wiley describes is one's ability to comprehend and communicate about spatial properties. Our research concentrates on the first three stages of Figure 2: visual perception, visual memorization, and visualization. Particular emphasis is placed on visualization as it is at this stage that a child must mentally manipulate images. Performance (externalization, transmission, reception and resolution) is a result of the child's ability to successfully complete the first three processes.

**Visualization and Imagery**

Visualization has been described as the "inner landscape of our perceptions." (Samuels & Samuels, 1975). It is the personal process of internally perceiving the essence of an object, person, concept, or process (Kosslyn, 1983). With regard to cognition, establishing a base understanding (i.e., essential knowledge) allows the individual a firm platform from which to explore permutations of that knowledge.

Visualization is a more complex version of simple imagery. Imagery consists of those mental images that are produced by memory or imagination (Samuels & Samuels, 1975). Visualization takes these mental images and adds an affective, almost visceral component, making the image stronger and potentially more meaningful. In other words, the process of visualization has the ability to generate physiological and emotional responses similar to that which we experience during "real-time" perceptions, i.e., those that are occurring and we are experiencing at the same time, vs. those that we reconstruct in our minds. For example, the fear that we feel while having a nightmare is just as "real" as the fear we might experience if what we were dreaming were actually happening to us.

Visualization is a directed process that an individual can undertake towards the goal of greater understanding or meaning-making. It opens the door to creating a dialogue with our perceptual senses. In Gagne's Memory Model (Gagne', 1985), sensory input is illustrated as a monodirectional flow. In contrast, an expanded model would recognize that by using visualization, we can actually create perceptual sensations that embody experiences created entirely in our mind.

Since visualization is a directed activity, does this mean that it is a conscious activity? Not necessarily; some of our best problem-solving is done while dreaming, a state under the domain of the unconscious (Samuels & Samuels, 1975). There are also substantial questions about the hypnotic state; is it conscious or unconscious? Can we visualize when in a hypnotic state?

There is no doubt that visualization, as a manifestation of the mind, is an intensely personal and highly individual activity. I am interested in whether that activity be guided by an outside source, such as a teacher, a software program, or in an entirely constructed environment such as virtual reality? How does it relate directly to education and learning? Can it be channeled to effect cognition? Most of the literature seems to indicate that, indeed, visualization and cognition relate to one and other. The key, then, is to determine the relationship, as well as other criterion that will facilitate use of visualization as a cognitive aid.

**Visualization & Cognition**

Visualization can be used to enhance many aspects of an individual's life: physically, spiritually, and mentally. In an intellectual sense, it can be used to develop focus, establish connections and relationships, and for creative problem solving, concept enhancement, and memory enrichment. (Kosslyn, 1983).

The relationship between visualization and cognition really rests on the concept of representation. Gagne' describes at least three types of representative knowledge: propositions, productions, and continuous knowledge (such as images and sounds) (Gagne', 1985). Regardless of how these representations are stored in long-term memory, they can be recalled in their representative form to short-term memory for contemplation or action. Visualization can use information from long-term memory, as well as new information gleaned from the environment to create new knowledge and understanding. Denis (1991) states:
"It will come as no surprise that in the context of a discussion about imagery the definition of "thinking" used here will hinge on the notion of representation. A convenient distinction is often made between long-term and transient representation. Long-term representations are the constituents of individuals' permanent knowledge, and transient representations are built up from new informational inputs. Representations are the locus of application of processes, which manipulate and transform their content in order to derive new pieces of information. Thinking is that set of mental activities involved in the manipulation of representations with the construction of new pieces of information as outputs, which can enter into an individual's knowledge base." (Denis, 1991, p. 103)

He follows this section on thinking with an erudite view of the relationship between imagery and cognition:

"My argument is that imagery is a set of processes which have their own properties, and can be brought into play at various levels of cognitive activity. Thus, imagery is not the core of thought processes, but rather a potential medium for them. Thinking makes use of representations, some of which are produced by imagery processes, and some by more abstract representational systems. Images, then, are models for thinking. It is recognized that although models are situation-specific, they can nevertheless be used to generate valid conclusions or decisions much beyond their specific content. In addition, models relying on imagery are more than static cognitive entities, but should rather be viewed as representations which enter into dynamic simulations and manipulations." (Denis, 1991, p. 104)

Dynamic mental "simulations and manipulations" have been used to solve intensely complex problems by creative individuals throughout history. By shifting perspective, and by determining whole-to-part relationships, critical questions have been answered. For example, the mathematician Poincaré and the physicist Feigenbaum used such a technique when developing their respective descriptions of geometric space and universality. In art, the same relationship holds. Tufte quoted the artist Paul Klee as saying:

"It is not easy to arrive at a conception of a whole which is constructed from parts belonging to different dimensions. And not only nature, but also art, her transformed image, is such a whole. It is difficult enough, oneself, to survey this whole, whether nature of art, but still more difficult to help another to such a comprehensive view. This is due to the consecutive (linear) nature of the only methods available to us for conveying a clear three-dimensional concept of an image in space, and results from deficiencies of a temporal nature in the spoken word." (Tufte, 1990, p. 15)

The discussion surrounds one's ability to envision both the detail, and the whole; to recognize the patterns and relationships that exist in nature, as well as in our minds. We need to ascertain what details are needed to understand the essence of a thing. To complete this thought, we turn to Feigenbaum:

"In a way, art is a theory about the way the world looks to human beings. It’s abundantly obvious that one doesn’t know the world around us in detail. What artists have accomplished is realizing that there’s only a small amount of stuff that’s important, and seeing what it is. So they can do some of my research for me...I really do want to know how to describe clouds. But to say there’s a piece over there with this much density, and next to it a piece with this much density -- to accumulate that much detailed information, I think is wrong; it’s certainly not how a human being perceives things, and it’s not how an artist perceives them. Somewhere the business of writing down partial differential equations is not to have done the work on the problem...Somewhere the wondrous promise of the earth is that there are things beautiful in it, things wondrous and alluring, and by virtue of your trade, you want to understand them." (Gleick, 1987, p. 186-87)

From these testimonials, it seems clear that visualization can be used to enhance one’s cognitive processes, by removing the "shroud of mystery" surrounding whatever it is that the individual would like to understand more fully. Specific literature regarding visualization and cognition per se is spotty; and literature regarding guided visualization and cognition is almost non-existent. What is presented below is the culmination of numerous library searches, and yet seems only to scratch the surface potential of combining one’s “inner sightedness” and mental machinations for cognitive gain.

**Visualization & Cognition Research**

### Externally Directed Guided Visualization Research

Regarding guided visualization and cognition, Gaylean (1982-83) has performed some of the only research combining the two topics. In her study, teacher-presented guided imagery was used as a learning aid in both elementary and secondary schools. The visualization exercises were designed to help students learn more effectively, to become more self-aware, to become more aware of others, and the perspective of others. Imagery activities took place as a preparation to learning, and also within the "lesson itself."

The study showed that visualization had a number of benefits, including less disruptive classrooms, increased cognitive achievement, and a greater feeling of warmth and cohesion between the students, and between students and teachers. They also found that everyone felt successful, because they "saw" things in their own personal fashion; there was no right or wrong way to image. Creativity increased, as did the "expression of unique ideas." Increased depth was also cited as a benefit.

That same year, Sadowsky (1983) studied 45th graders and their ability to generate creative endings to a story. All subjects were tested for verbal mental ability, and interviewed as to their naturally occurring mental images. A story was presented to both an experimental and a control group, where the experimental group was encouraged to visualize potential endings to the story.

The results indicated that those who imagined different endings had had to pay more attention to the details of the story as it went along, and were able to generate meaningful, elaborate, and feasible endings. The researcher concluded that deeper semantic processing was occurring with those that were visualizing.

The study also pointed out that traditional testing for reading comprehension may be incomplete, in that tests often are looking for verbal mental responses, when in fact mental images created during story reading may be valid measures of comprehension as well.

In a study by Saarnio & Bjorklund (1984) on guided visualization and recall, kindergarten, 2nd grade and 5th grade children were tested for their ability to remember objects in a story by creating their own mental images. The researchers found that recall improved as organization strategies were used as guides. However, further investigation revealed that it was not organization within the scene that enhanced recall. Rather, it was the children’s ability to mentally generate *interrelating connections* between the objects themselves that yielded the best results.
Internally Directed Visualization Research

There are also several studies that describe children's attempts to visualize without any external guidance, i.e. using their own imaginations as their guides. A selection of those studies is presented below.

In a study regarding the relationship between spatial performance and ability conducted by McClurg & Challé (1987), computer games were used to test whether the spatial nature of the games would enhance the spatial abilities of 5th, 7th, and 9th graders, as measured by the Shepard & Metzler (1971) Mental Rotations Test (i.e. whether performance would effect ability.) Two computer games were used. Both could be played at a variety of difficulty levels. One game was a factory that made punched items that varied in complexity. Students had to design a manufacturing environment that would create a pre-specified object. The other game was a space warfare game, which included a universe in which the game is played, and a plethora of entities; some good, some bad, and some that could even transform themselves into other entities.

Spatial effects present in the games included visual perception and discrimination, differentiation of opposite obliques, visualization of transformations in series, the use of referent systems, and the development and updating of cognitive maps.

Results indicated that all of the students benefitted from playing the games, regardless of grade or sex. The authors note that developing computer games that motivate little girls to play as much as little boys would "level the spatial playground."

Brodsky, Esquerré & Jackson (1990-91) have studied individuals who are able to undertake a state of being called "lucid dreaming". In essence, this is a dream state that is consciously directed from within the individual. The individual can draw on memories, but can also engage creative thinking skills and the freedom of thought inherent in the unconscious to solve problems, solutions to which are remembered upon waking. It should be noted that attitude also played a role here; those individuals who thought their dreams were important prior to the study were more attuned to what occurred during the experiment. This may indicate that not everyone (at least those who do not feel their dreams are important) could engage in lucid dreaming.

Dwyer (1988), makes an important point regarding the use of visualization as a potential learning tool. Though he feels that visualization "represents only a mild rehearsal strategy which will not always optimize student achievement of the more complex levels of learning", he also feels that if "visualization is used in the encoding process, then it ought to be used in the retrieval phase of the teaching/learning process." This point speaks directly to the design of assessment mechanisms that are related to how the material was learned, rather than for the convenience of testing and scoring. It could be at the heart of why so many visual processors do poorly on written (verbal) assessments.

There is also a body of research regarding what it is that the blind see with their minds eye. Kennedy (1983) conducted a study in which congenitally blind individuals were asked to visualize particular objects in their mind's eye, then draw them on paper. The results indicated that these individuals used a universally recognizable outline form to convey the images that they saw in their mind, and that the drawn images were reasonable, accurate, and understandable. This might mean that guided visualization could be used even with children with disabilities (such as blindness) as an aid to cognition.

In another study on congenitally blind individuals and their ability to visualize, Zimler & Keenan (1983) compared congenitally blind vs. sighted individuals who were asked to perform three different tests, all of which involved visualization of objects.

In all cases, the blind individuals did better than sighted individuals recalling concepts that were auditory in nature. However, when comparing visual, haptic, and auditory concept recall, blind subjects remembered more visual concepts than concepts in any other category.

This led the researchers to believe that blind people do in fact visualize, at least in a fashion that works for them. The conclusions are that visualization is highly individualized, and that meaning can be developed regardless of the sense modality used to encode the information to begin with. Furthermore, visualization is a naturally occurring event, even in individuals blind from birth.

The Computer-Based Learning Environment

It is important that the environment in which a child is expected to learn be conducive and supportive of the learner. With regard to computer-based learning environments, Siegler (1978) has presented examples of child-computer interactions, and has addressed problems related to children's perception of computer controls. In his work, he has identified aspects of children's object-based reasoning and decision-making processes, providing support for the importance of problem solving/object manipulation skills as a basis for other forms of cognition. Lawler (1985) has also done work in this area, on children's perceptions of computer tasks.

The work of McClurg (1992) is based on the use of computer-based spatial cognition training. In her study, third and fourth-grade students were given the opportunity to work with spatial processing software programs as an enhancement to their spatial processing ability. Spatial visualization skills were measured using the Black & Black Figural Classification Test (1984), and the Shepard & Metzler Mental Rotations Test (1971). Results indicated that the skill level of all children who worked with the software had been enhanced beyond the levels achieved by children who did not work with the problem-solving software.

Though both standard and multimedia computer environments have a more firmly established base (and a greater amount of research that has been done regarding their effectiveness), we are very interested in the virtual environment for a number of compelling reasons. First, as stated by Winn & Bricken (1992), "the programmability of VR allows a curriculum designer to embed pedagogical strategies into the behavior of virtual objects." (p. 12). Furthermore, the work of Regian et al (1992) indicates that virtual reality is indeed a superior environment for spatial skills enhancement, specifically because "the interface preserves (a) visuo-spatial characteristics of the simulated world, and (b) the linkage between motor actions of the student and resulting effects in the simulated world." (p. 136) Their research also indicates that, when presented with similar spatial processing tasks in both a two-dimensional "god's-eye view" world, and a three-dimensional virtual world, performance is qualitatively and quantitatively better in the virtual environment.

Middleton (1992) also seems to feel that the attributes of virtual reality make it an ideal learning environment. She describes these attributes as:

_ Great flexibility in the creation of virtual or artificial worlds;
_ The ability to support a felling of presence;
The ability it gives the user to control and interact with objects and people within the virtual world; and

_ The physical feedback from objects and people within the world. (Middleton, 1992, p. 254)

In her work at the Stanford Research Institute, she is actively pursuing a deeper understanding of how these attributes can contribute to the learning process. And Jaron Lanier (1992) has worked directly with fourth and fifth graders to develop learning environments that change the "situation" to foster greater retention and recall.

Our goal is to get the child to "suspend belief" long enough to learn spatial problem solving skills in a simulated environment. In the words of Brenda Laurel, this level of engagement is best described through the analogy of theatre:

"Coleridge believed that any idiot could see that a play on stage was not real life. (Plato would have disagreed with him, as do those in whom fear is induced by an new representational medium, but that is another story.) Coleridge noticed that, in order to enjoy a play, we must temporarily suspend (or attenuate) our knowledge that it is "pretend." We do this willingly, in order to experience other emotional responses as a result of viewing the action... The phenomenon that Coleridge describes can be seen to occur almost identically in computer games, where we feel for and with the characters (including ourselves as characters) in very similar ways." (Laurel, 1991, p. 113)

Virtual reality can potentially provide such an environment. In discussing the dimensions of telepresence, Steuer (1992) says that vividness and interactivity are both positively related to a sense of "being there." However, these components can be overridden, resulting in sensory overload for the participant. There is a careful balance to be maintained.

Bricken (1991) describes the potential of virtual worlds as learning environments, in relationship to educational theory and pedagogical practice. The work of Bricken (1992), Bricken & Byrne (1992, 1993), Byrne (1993) and Osberg (1992, in press) illustrate that children not only can effectively manipulate objects and events in three-dimensional space, they enjoy it immensely as well.

The Experiment

Recall that the primary question we are asking is can thinking intensively about spatial concepts enhance spatial cognition? The bulk of the research described above indicates that other studies have shown a positive relationship between spatial exercises and spatial skill enhancement. We wanted our intervention to have just as positive an effect, especially for the type of children with which we were working. These children were selected because of their spatial processing problems, and therefore had the most to gain from such an intervention.

Puzzle World: A Game with a Goal

Our initial task analysis resulted in a clear need to develop a process that was engaging, interactive and effective. We chose to teach the children how to create puzzle pieces that would fit together, both on an individual and on a group level. The goal was to develop enough continuity from child to child that each time someone would experience the completed world, they could configure it in a manner of their choosing. By providing such a simplistic goal as a starting point, we were able to develop buy-in with the children right away. All of them had worked with puzzles before, and understood that the pieces needed to fit together to form a cohesive whole. Most of them found it exciting to develop a puzzle that wasn't just a flat picture.

Furthermore, creating puzzle pieces as a group provided the children with an opportunity to communicate about what they were making, and how they were going about their creation process. We were hopeful that this mix of "declarative" and "procedural" information would encourage the children "to take existing knowledge, and those cognitive processes that operate on it, and changing its representation." (Lopez, 1992, p. 181)

Though the body of literature on experience in VR, and especially children's experiences, is limited, there are some excellent resources on which to base our design. Children's behavior in the game can be predicted through some of the research performed by Hirose et al (1992). Object manipulation, physical constraints, mapping to the physical world, and perceptual input/response are discussed. Merickel (1992) has recently completed one of the few empirical studies on children's perceptions in the virtual world. In it, he describes how training in visualization and mental manipulation can enhance spatially related problem-solving skills, both in two and three dimensions. There has even been some research regarding the metaphors used to develop a relationship between the virtual environment and the user (Bell, 1993).

Of course, there are those who downplay the entire notion that such learning can be had, either in a multi-media environment, or in the virtual world. Trotter (1991) has little good to say about even such widely known and respected problem solving programs as "Where in the World is Carmen Sandiego?" Even Lanier & Biocca (1992), voice some concern over the role of present-day interactive video game technology and virtual reality in a child's life.

However, the research indicates that the technology has some unique aspects to offer with regard to spatial cognition. Indeed, some of the finest minds in history have used visualization as a process to expand their perspective, to focus in on details, and to expand their understanding of the world.

Therefore, I hypothesize that by teaching children how to think in three dimensions, using visualization techniques and a lot of practice, we can enhance their spatial cognitive abilities, and have a positive effect in other areas of their lives as well.

Method

Subjects

The subjects for this study were 10 11-14 year-old students, 9 males and 1 female. These children were associated either with the Children's Institute for Learning Differences, (CHILD), a private non-profit educational institute located in Bellevue, WA, or in treatment with Ms. Judith Rabinovitch, a neuro-development therapist. Approximately 60 children ages 3-14 attend CHILD during the regular school year. The children selected for the study were those with moderate to severe spatial cognition problems. Most had attended the summer program at CHILD, at the
conclusion of which was the Puzzle World development class. There were two instances of subject attrition during the course of the study; these two children refused to complete the post-test, and so were dropped from consideration with regard to the results. This age group was selected because it represents a group of subjects at the crux of adolescence, the age corresponding to the ability to undertake abstract or symbolic thinking, which requires spatial cognition (Piaget, 1952), (Bruner, 1966).

CHILD was selected because of the special population that they serve. Students attending CHILD are all in need of some type of therapeutic intervention to assist them academically, and often behaviorally as well. Furthermore, I had an established relationship with the Director of the school, facilitating both our mutual understanding about the goals of the project, and our ongoing communication before, during, and after the project.

Choosing puzzles as the subject of interest was predicated upon our desire to select a subject that would be engaging, encourage interactivity both at the personal and at the group level, and would require spatial processing skills. Our assumption was that these subjects would have had experience with both 2-D puzzles (such as tangrams or the standard create-a-picture version) and 3-D building blocks such as legos, both of which were true in all cases. This pre-existing knowledge would assist the subject in better understanding the process necessary for designing and building a virtual world.

No incentives were offered to either the teachers, the teaching assistants, the camera man, or the subjects. All of the subjects received the same intervention. No control group was available, due to subject availability and time constraints.

**Instrumentation**

All students were pretested for visual ability, sensory-motor skills, and spatial cognition. In addition to tests performed on or by the individual, a parent checklist was submitted, detailing both current and early childhood behaviors. An example of the parent checklist has been included as Appendix A.

The parent checklist, vision screening, and sensory-motor skills assessment were done to give us a better “profile” of each subject. Because each of these children has such an interesting (and varied) background, we felt it was best to gather as much information up front as we could, in the interest of making better statements at the conclusion of the research. The only assessment instrument that was used as a measurement device was the Inventory of Piaget’s Developmental Tasks (IPDT) (Furth, 1970).

The vision test was performed by a licensed developmental ophthalmologist. Subjects were tested for visual acuity, hyperopia, and stereopsis. Of particular interest with regard to spatial cognition was the individuals’ binocular disparity and accommodative abilities. The screening was performed in a small room that could be darkened at CHILD. An example of the vision skills tested is included as Appendix B.

Sensory-motor skills were tested using excerpts from Rabinovitch’s Intervention in the Holistic Approach to Neuro-Development and Learning Efficiency (I HANDLE) (Rabinovitch, 1992). What we were trying to ascertain was where each subject stood with regard to their attentional priorities, ability to differentiate, and degree of lateralization and integration. Each subject was tested individually, with the assistance of an administrator. All of the subjects were video-taped for later confirmation of results. An example of the modified I HANDLE is included as Appendix C.

Spatial cognition skills were tested using the Catholic University Center for Research in Thinking and Language version of “An Inventory of Piaget’s Developmental Tasks” (Furth, 1970). This is a 72-item, paper-and-pencil inventory, dealing with 5 specific spatial problem areas: conservation, images, relations, classification, and laws. It was originally designed to test Navajo children for task comprehension while minimizing the potential problem of language as a barrier. The test is divided into 18 different subtests, each of which is designed to address one of the five problem areas. They are presented in order of increasing difficulty within the inventory. Though most children should be able to accurately complete each subtest by the age of our subjects, research by Neo-Piagetians such as Case (1984, 1985, 1987) and Siegler (1986, 1987) indicated that age is less important than understanding content within structure, or having had the opportunity to work with and solve similar problems. A subtest summary is listed in Table 1.

In a reliability and validity assessment of the IPDT, Patterson and Milakofsky (1980) were able to show that the inventory does indeed tend to track children’s progressive assimilation of the spatial tasks tested over time. They used the inventory to assess the performance of 250 third, sixth, and ninth graders, 210 college freshman and sophomores, and 22 “educably retarded” individuals.

Reliability assessments were computed by using several different forms of the test given in a group setting, in combination with a “modified” version of the test given on an individual basis. Subjects were rotated through 3 different testing scenarios over the space of one month. By comparing the results of these tests, Patterson and Milakofsky were able to conclude the inventory had “reasonable reliability over a short period for a wide range of age groups, that does not seem to be affected by situational testing variables.” (p. 348) Concurrent validity was tested by comparing Group versus individual scores. No significant difference was found between the two scores, indicating that scores were valid across the group tested.

Table 1

<table>
<thead>
<tr>
<th>Content Summary of the IPDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Milakofsky &amp; Patterson, 1979)</td>
</tr>
</tbody>
</table>

Approximate

Subtest Subtest Problem Concept Mastery
<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Area Assessed</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Quantity Conservation</td>
<td>7-8</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Levels Images Transformation</td>
<td>9-10</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Sequence Relations Ordinal Relations</td>
<td>7-8</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Weight Conservation</td>
<td>9-10</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Matrix Classification</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Symbols Classification</td>
<td>Combinativity</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Perspective Images</td>
<td>Perspective</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Movement Images</td>
<td>Kinetic Imagery</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Volume Conservation</td>
<td>Conservation</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Seriation Relations Ordinal Relations</td>
<td>7-8</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Rotation Laws</td>
<td>Kinetic Imagery</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Angles Laws</td>
<td>Reciprocal</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Shadows Images</td>
<td>Perspective</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>Classes Classification</td>
<td>Classification</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Distance Conservation</td>
<td>Conservation</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>Inclusion Classification</td>
<td>Verbal Class</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>Inference Relations</td>
<td>Verbal Transitivity</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>Probability Laws</td>
<td>Probability</td>
</tr>
</tbody>
</table>

Construct validity was tested by looking at the mean scores for each group, as well as the disparity from group to group in terms of "mastery." Using 75% correct (3 out of 4) as an indication of mastery for a particular subtest, 15 out of 18 concepts (83%) were mastered by college students, 12 out of 18 (67%) by ninth graders, 5 out of 18 (28%) by sixth graders, and none by the third graders. Mastery clearly increases with age, with large incremental leaps present between grades 3, 5, 9, and at the beginning of college (Patterson & Milakofsky, 1980).

With regard to the "educably retarded" children and adults, "it would appear... that the IPDT could be of use in identifying particular strengths for mildly or moderately retarded children and adults."

Based on this assessment, especially since the test had included individuals with learning problems, we felt that it would fulfill our need for spatial cognition assessment tool.

**Materials**

Each subject received a workbook containing schedule information, visualization exercises, a reference card for the software used to build the 3-D objects, a set of 3-D design exercises, drawing paper, and writing paper for making journal entries. Included at the back of the workbook was a tab for each subject’s three-dimensional design print-outs. The notebook was theirs to keep at the conclusion of the class.
These workbooks were used to keep the subjects aware of the schedule, to develop an awareness of how the design software worked, as a mini-manual for the software, and to provide a place to draw or write throughout the class. The Examples section of the binder was the most valuable in that it was used to “jump start” the children, allowing them to create meaningful objects from physical examples in the software package, within a very short (less than an hour) period of time. These examples are included in Appendix E. All of the subjects illustrations, notes, and designs were either copied or transcribed, with their permission.

Virtual puzzle pieces were created with the assistance of Swivel 3-D (version 1.5.80), a three-dimensional software program specifically written as a front-end design tool for virtual reality. The base world was also created in the same package. Swivel 3-D runs on the Macintosh platform, and requires a computer with at least 5 megabytes of RAM. Proprietary conversion and rendering software were provided by the Human Interface Technology Laboratory and Division, Inc.

Procedures

Pre-tests were conducted at CHILD approximately 2 weeks before the Puzzle World class started. All available subjects were rotated through all three (vision screening, sensory-motor skills, and the IPDT) stations on a round-robin basis. Subjects not available at the time were tested on an individual basis prior to the start of the class. Parent checklists were sent out and returned to us before the start of the class.

Due to the great interest in this study by professionals both at CHILD and within Ms. Rabinovitch’s practice, we were able to provide 3 educational professionals in addition to the researcher as teachers in the class. These four professionals chose to team-teach the class as much as possible. All four were involved in the administration of the pre-tests for sensory-motor development, and the IPDT. In addition to the four educational professionals, we were also assisted by an intern from the Human Interface Technology Laboratory at the University of Washington. Video footage was taken by a film writer and producer who was visiting from Los Angeles for the summer.

Class met each day from 9 a.m. to 3:00 p.m. in the Computer Lab at the Forest Ridge Academy in Bellevue, WA. Each day was subdivided into “activity” and “thinking” periods. At the beginning of each day, the children had a chance to write in their journals. Frequent breaks were taken so that children could “reorient” themselves in the physical world. Lunchtime was spent outside, so that the children most in need of some room to run could do so.

A daily schedule is included in Appendix D, but a brief overview of the training process is presented here. On the first day of class, we spent a great deal of time talking and thinking about the software that we were using, and how we could make three-dimensional objects that appear on a two-dimensional screen. After a brief overview of the functions available in Swivel, the children dove right into the computer program, developing their first 3-D objects. Later that morning, we went through the example objects one by one, those illustrated in Appendix E. For all of the objects in the Examples section, I had a physical example to show to the children. We looked at the example and described how each “face” (top, front, and side views) were different, and how when combined they formed a composite whole. The examples became increasingly more complex, and required the children to use different tools in the software to create them. By the time they could create a fish, they had a fair idea of what the tools could do for them, and how different “faces” can combine to create a whole. In other words, the point was to allow the children the opportunity to consider deconstruction and construction of objects, using these conceptions to create the objects using whole-to-part reasoning.

There was plenty of time for the children to work with the software; in fact there was too much time. When they got tired of designing Swivel objects, many of the children played SimCity, a well-known computer game that happened to be resident on the computers in the lab.

At the close of the day, children once again had the opportunity to write in their journals about their experience. Though I had hoped for a rich, textual account of the days activities, I was sadly disappointed. Most of the children wrote one line, and though all of the comments were very positive, I still wished for more depth.

On the second day, the children convened as a group, to discuss the type of puzzle world they would like to build. We got a lot of interesting suggestions, but the discussion indicated that it was difficult for these children to think holistically, in concert with all 9 other individuals with whom they were working. One of the adults suggested that the children create animal “pieces” that could be combined to form new non-biological terrors. The children were not impressed. What became clear over time is that each child had their own idea about what they wanted to create. Instead of insisting on group-level consensus, we decided that the value of the process was primarily for personal spatial cognition enhancement, so agreement on the “big picture” became less important. We let their individual selections stand.

The next two days were spent in intense, feverish development of several individual “worlds.” I had directed them to start small, to make just a few objects. When they felt more comfortable, they could begin to combine objects together, forming a “world.”

Midway through the fourth day, the combined Puzzle World was created from all of the disparate pieces. The morning had been spend selecting the “world” that each child wanted to contribute, naming all of the objects in that world, printing it, labeling it, and turning it in to me on disk. The procedure of building the base world, and combining the objects in an aesthetically pleasing manner would normally have been a job for one or two of the children. However, there was considerably less interest in others’ objects with this group of children than with other groups with which I have worked. This is consistent with their original insistence on completing objects individually rather than as a group. I have no explanation for the difference.

Because of some of the difficulties that these children faced, following simple instructions was a real trial. Creating the finished product that contained everyone’s contribution was a task that is highly procedural, and requires a lot of administrative overhead on the part of the children. Though I had to repeat myself (up to 6 times with one child) we finally got it done. The children went on a field trip; I went to the HIT Lab.

Swivel allows the user to output the 3-D graphic file into a text file containing all of the instructions for the graphics renderer to re-create the images in the virtual world. Using the children’s disk, I (with the infallible assistance of Marc Cygnus) converted the file to the format needed by the Division system, to run on a stand-alone virtual reality rendering engine called the ProVision 100. The system is an excellent platform in which to work with children, primarily because it is bombproof. High-tech gear that can break easily is just too risky to use with young children, particularly adolescent boys. We were fortunate to have access to the Division system.
After some final rearrangement of the objects, Puzzle World was ready. On the last day, the children experienced their constructed Puzzle World through helmet and wand, in virtual reality.

At the conclusion of the class, eight of the ten children were post-tested using the IPDT. The other two children refused to finish the test. Therefore, the data set includes eight individuals, all male. Personal interviews, however, were conducted with all ten children. We were able to gather anecdotal information about their experience, what they had learned, what they had liked, etc. Their responses were no different from any of the other 60 children with whom I have spoken about virtual reality in general-- almost all of them think it is a truly wonderful experience.

Results

Results from the IPDT pre- and post-tests are illustrated below. The results are presented by subgroup.

### Table 2

**Mean Scale Scores for Total Sample by Subgroup**

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Pretest Mean</th>
<th>Posttest Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Name Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Quantity Conservation</td>
<td>2.875 (.835)</td>
<td>2.875 (.835)</td>
</tr>
<tr>
<td>2 Levels Images</td>
<td>3.250 (1.061)</td>
<td>3.625 (1.061)</td>
</tr>
<tr>
<td>3 Sequence Relations</td>
<td>2.625 (1.389)</td>
<td>2.750 (1.389)</td>
</tr>
<tr>
<td>4 Weight Conservation</td>
<td>2.875 (1.408)</td>
<td>3.375 (1.408)</td>
</tr>
<tr>
<td>5 Matrix Classification</td>
<td>3.000 (1.165)</td>
<td>3.250 (1.165)</td>
</tr>
<tr>
<td>6 Symbols Classification</td>
<td>2.125 (1.389)</td>
<td>2.875 (1.389)</td>
</tr>
<tr>
<td>7 Perspective Images</td>
<td>2.875 (1.753)</td>
<td>2.750 (1.753)</td>
</tr>
<tr>
<td>8 Movement Images</td>
<td>2.750 (1.581)</td>
<td>2.750 (1.581)</td>
</tr>
<tr>
<td>9 Volume Conservation</td>
<td>2.250 (1.414)</td>
<td>2.000 (1.414)</td>
</tr>
<tr>
<td>10 Seriation Relations</td>
<td>3.250 (1.035)</td>
<td>3.250 (.886)</td>
</tr>
<tr>
<td>11 Rotation Laws</td>
<td>1.375 (.641)</td>
<td>2.125 (1.458)</td>
</tr>
<tr>
<td>12 Angles Laws</td>
<td>2.500 (1.165)</td>
<td>2.750 (1.165)</td>
</tr>
<tr>
<td>13 Shadows Images</td>
<td>2.250 (1.512)</td>
<td>2.500 (1.512)</td>
</tr>
<tr>
<td>14 Classes Classification</td>
<td>1.500 (1.246)</td>
<td>1.875 (1.246)</td>
</tr>
<tr>
<td>15 Distance Conservation</td>
<td>1.875 (.916)</td>
<td>2.375 (.916)</td>
</tr>
<tr>
<td>16 Inclusion Classification</td>
<td>2.750 (1.518)</td>
<td>3.625 (.518)</td>
</tr>
<tr>
<td>17 Inference Relations</td>
<td>1.195 (1.282)</td>
<td>2.750 (1.282)</td>
</tr>
<tr>
<td>18 Probability Laws</td>
<td>2.000 (1.035)</td>
<td>2.250 (1.035)</td>
</tr>
<tr>
<td>Total Scores</td>
<td>45.000 (15.012)</td>
<td>49.75 (15.012)</td>
</tr>
</tbody>
</table>

*Note.* Standard deviations in parentheses.
Though the mean scores in each subtest do not vary significantly, a two-tailed $t$ test comparing total mean scores indicates significance, $t = 5.16$, $df = 7$, $p < .001$.

Though we were interested in spatial cognition in a general sense, we were also interested in a set of specific spatial processing skills: spatial relations, sequencing, classification, transformation and rotation, whole-to-part relationships, mental imagery, and creative problem-solving.

Spatial relations were defined as an understanding about the relationship between objects in space, both in dynamic and static environments. This is one of the primary components of spatial cognition, and is dependant upon most if not all of the skills described in the subtests above. I feel that the total scores for the IPDT are indicative of the children's improvement in understanding spatial relations as a whole.

Sequencing was defined as understanding the order of both objects and events. The sequencing subtests (3 and 10) indicated only slight improvement in the children's ability to sequence.

Classification was defined as the ability to comprehend relationships between objects and to develop meaningful groupings, as a means of developing mental order. In each of the classification subtests (5, 6, 14, 16) There was improvement; probably the strongest improvement that we saw in any one group of subtests. This may be due to the nature of the type of world we developed; puzzle pieces need to fit together; to be of the same "class" of objects. It would be interesting to study how development of different types of worlds would affect the results.

Transformation and rotation is the ability to mentally transmute an object from one state to another, without the need for physical representation of the transformation. Transformation and rotation subtests (2, 8, 11, 12, 17, and 18) indicated improvement in every subtest but 8, in which the results remain the same.

Visualization was defined as the ability to construct, manipulate and interpret images in the mind. As is true with spatial relations, we felt that the IPDT as a whole represents gains in the area of visualization.

Creative problem solving was defined as the external manifestation of all of the above activities coupled with reason. There was a great deal of creative problem solving going on in the classroom - much of it captured on video tape. The children would often verbalize their accomplishments to their seat-mates, or to one of the instructors. In most cases, we were able to get the child to describe how they had found solutions to the design or technical problems. What these children lacked in spatial ability prior to the class, many of them made up for it in sheer determination to design what they wanted to design.

We had wanted to select a design goal that would provide the children with a sense of engagement, interactivity, and that would provide an opportunity for problem solving. Given the results, I would say that we were successful with regard to the engagement factor, and that problem-solving was a big part of what transpired that week. I am less convinced regarding interactivity. Thought the children were fully engaged in their own projects, it was difficult to develop a sense of group interaction. These children all have different issues, and seemed to naturally fall into 4 subgroups as a matter of course. Conversations were frequent within subgroup, but discussion across subgroups was almost nonexistent.

The most telling comparison that I have made is to compare the mean scores of this group with the mean scores of the sixth and ninth graders tested by Patterson and Milakofsky, as presented in Table 3. The average age of the eight remaining children in the post-test group was 13.33 years.

Table 3

<table>
<thead>
<tr>
<th>Mean Scale Scores Comparison on Selected Subgroups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study P &amp; M Study P &amp; M</td>
</tr>
<tr>
<td>Pretest Grade 6 Posttest Grade 9</td>
</tr>
<tr>
<td>Mean (13.3) Mean (11-12) Mean (13.3) Mean (14-15)</td>
</tr>
<tr>
<td>Volume 2.250 1.98 2.000 2.65</td>
</tr>
<tr>
<td>Rotation 1.375 1.70 2.125</td>
</tr>
<tr>
<td>Classes 1.500 1.73 1.875 1.95</td>
</tr>
<tr>
<td>Distance 1.875 2.18 2.375</td>
</tr>
<tr>
<td>Probability 2.000 1.91 2.250 2.80</td>
</tr>
</tbody>
</table>

*Note. Ages in parentheses.*
For the five most difficult subtests, our study group pre-tested below 6th grade average on three of the tests, and slightly above average on the other two. Post-test scores indicate that in all five domains, the group has improved beyond the 6th grade level, yet is still below the 9th grade level of achievement. It could be inferred that in fact, after having worked diligently to design and manipulate three-dimensional objects and environments, these children now have been able to achieve age-appropriate spatial cognitive skills.

Discussion

Though these data support the hypothesis that intensive training in three-dimensional thinking can help a child gain skills necessary for spatial cognition, it does not answer which particular component of the week-long program did the most good. Was it working in Swivel? Was it the workbook approach? Was the experiential nature of virtual reality?

Further research needs to be conducted, to establish the cause-and-effect relationships inherent in this type of experiment. In the interest of habituating these students, we wanted to give them the "full meal deal", just as has been done for a number of other children through the Pacific Science Center Creative Technologies camps (Bricken, 1992), Bricklen & Byrne (1992, 1993), (Byrne, 1993), (Osberg, 1992, in press). It is more important to identify the key elements responsible for fostering their spatial understanding, especially since these children are having a tough time making it in the academic world. Although no significant differences in subtest scores were observed, the most promising area for future study appears to be identification of the key elements that generated the significant improvement for the group as a whole. It will be interesting to note their progress over the course of the school year, as I am still closely involved with both CHILD, and Ms. Rabinovitch.

Furthermore, we do not know if these effects transfer to the general population. Results from Merickel (1992) others indicate that there has been positive effect in their research, but again, it comes down to identifying the critical factors involved.

The IPDT assessment tool appears to have value as a "readiness assessment" mechanism, which may help teachers better understand exactly where their students stand with regard to spatial and general cognition. In Grauer's work on creating conditions for learning in the classroom, he says that teachers need to become more environmentally and perceptually aware of the "learning state" of their pupils. He speaks to the subliminal nature of non-verbal cues, voice resonance and tonality, environmental cues (such as wall color and background sound), and even a learner's dietary needs. Regarding gauging learner readiness for thought, he states:

"Defining the conditions for learning or, more specifically, defining the level of perception, has become a far more scientific endeavor over the past few years." (Grauer, 1985, p. 10)

To his way of thinking, a teacher has a great deal of latitude in assisting the student not only to learn, but to open the doorway to be ready to perceive. Since one must be open to perceptions to learn, Grauer's approach seems much more appropriate with finding the actual rhythms at which a learner will attend and immerse him/herself in the educational material. This is an example of how the teacher affects the student, who in turn affects the teacher, and so on. Master teachers already co-exist with their students in such a fluid environment, but I submit that there is still much to be gained from actively reintegrating a visual component to learning back into the classroom, as can be seen from the results of this study.

In addition to research on appropriate methods of enhancing spatial cognition, I feel it is important to integrate learning style preference into the research as well. My hope would be to identify not only how one's learning preferences are established, but whether those preferences are "interchangeable" with regard to content, environment, temporal factors, and the like. In an optimum world, a learner would indeed be an adaptable being; ready to shift gears at a moments notice, and shift them based on their own ability to assess a situation and choose a direction. We become too locked in that which we know, and that with which we are comfortable. Our school systems often foster this mentality by drawing a very clear line around the expectations held by the teacher and results required from the student to be "successful." Perhaps if we begin to encourage children to think about how they think, and to actively contemplate subjects, events and feelings more deeply, a wonderful thing may occur. We may actually begin to feel free enough, and daring enough, to do the same.

References


(Not Available)

Appendix A - Parent Checklist
(Not Available)

Appendix B - Vision Screening Test
(Not Available)

Appendix C - Sensory-Motor Test
(Not Available)

Appendix D - Daily Schedule
(Not Available)

Appendix E - Swivel Examples
Human Interface Technology