<u>Virtual Reality and Education</u>

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Submitted to: Dr. James White

EME7938

University of South Florida
Fall 1999

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Introduction

Background

One of the challenges in working with instructional media is that developers and educators are confronted with a rapidly moving target in terms of information technology's capabilities. The business and entertainment sectors are driving a fast-paced evolution of the devices people have in their workplaces and homes. Researchers and educators are scrambling to assess the potential, develop pedagogical strategies, create instructional materials, and implement a school- based infrastructure for today's technologies— only to find that computers and communications are "morphing" into new media of even greater power. Students of today experience a society and a workplace that is entirely different from those that their parents faced. To allow educational tools to fall behind the pace of technological advance is to sell out a generation of learners.

People's understanding of what computers can do has shifted dramatically as the size and cost of these devices has decreased while their power has grown. First, computers were seen as number- crunching machines, then came data processing, now we live in the age of tools that manipulate symbols and information. Virtual Reality (VR) research is based on the growing certainty that the next evolutionary stage is computers and telecommunications fusing into virtual environments. "Cyberspace" is not simply a channel within which content flows, but a virtual place to live that competes directly with reality for the attention of many, especially new generation of students. For this reason, charting the strengths and limits of virtual reality is vital for educational technology.

Educating children now and in the future to live in an information society is critical. There is also a need to provide life-long education for all citizens and to support a flexible workplace. VR technology has been widely proposed as a major technological advance that has potential to support for such education.

There are several ways in which VR technology is expected to assist learning. Most importantly it allows students to visualize abstract concepts, to observe events at atomic or planetary scales, and to visit environments and interact with events that distance, time, or safety factor make unavailable. The types of activities supported by this technology promote current educational thinking that students are better able to master, retain, and generalize new knowledge when they are actively involved in constructing that knowledge in a hand on learning environment.

There is evidence that, in suitable application areas, VR can offer an effective medium for enhancing certain skills. For example, effectively coordinating sensory-motor skills; gaining situation awareness through use of simulations; and training in design skills. The commercial success of virtual environments in pilot training has led to speculations about the application (Krueger, 1991) of virtual environments to other areas of education, such as in virtual science laboratories. This kind of approach could give students access to virtual experiments involving the use of otherwise prohibitively expensive equipment. However, research concerning virtual environments to date has focused on skill acquisition, i. e. the development of coordinated sensory motor skills and situation awareness. Empirical evidence on the effectiveness of virtual environments for promoting learning of rich subject matters is limited.

Designers and evaluators of immersive VR systems have many ideas concerning how VR can facilitate learning (Dede, 1996b), but there is little information concerning which of the VR's features best enhance understanding or how to customize those affordances for different learning environments. Other factors such as the concepts or skills to be learned, individual characteristics, the learning experience, and the interaction experience all play a role in shaping the learning process and learning outcome.

This paper discusses the potential value of VR to education, starting with a description and an analysis of VR. Recent psychological theories of knowledge construction are described and then the nature of the confluence of VR and constructivist learning theory or the "goodness of fit" between the two is examined. A discussion on whether constructivism is the best basis for building a theory of learning in virtual environments is included. Finally, the effect of learner characteristics (e.g. learner age, gender, etc.) on learning through VR is investigated.

Approach

The literature search is designed to answer some of the most obvious but critical questions related to effectiveness of VR-based education. These questions include:

- Do learning in virtual learning environment offer advantages over more traditional methodologies?
- What implications for learning do immersive virtual world offer?
- Which learning rationale is the most suitable for VR environments?
- How does student effectiveness of virtual world compares with other instructional practices?

- What is the impact of learner characteristics (e.g. age, gender, race, or previous experience) on learning in VR? What types of learners benefit from VR?

Scope of the Study

The term "Virtual Reality" has been applied more widely to include graphics applications that allow users to walk through a simulated environment and, possibly, to interact with objects in it. Therefore, this paper is concerned only with immersive VR.

In addition, this paper will include both educational uses of VR technology and training applications, but not with those instances where VR technology itself is being taught, but rather where VR technology is being used as the learning medium.

Literature Review

What is Virtual Reality?

The early stages of development of any new technology or theory are often confounded by controversy over what that technology actually involves. Any definition of VR is further confounded by an assertion that it is not a technology, but other set of emerging phenomena which are enabled by another set of rapidly developing technologies and informed by yet another complex set of socio-cultural influences. VR is a set of rapidly developing computer-generated phenomena in search of a definition.

Popular representations of VR (in advertising and movies) are unrelated to today's VR capabilities. The technology's undeveloped state seems to be the only barrier to the achievement of the science fiction fantasies that are provided by the current press. A survey of the literature on VR does reveal some recurring themes.

VR may be seen as a form of human-computer interface characterized by an environmental simulation controlled only in part by the user (Spring, 1991). VR requires hardware and software that furnish a sense of (1) immersion, (2) navigation, and (3) manipulation (Helsel, 1992). VR falls into three major categories: text-based, desktop and immersive VR. *Text-based networked* VR involves real-time environments described textually on the Internet where people interact by typing commands and "speak" by typing messages on their computer keyboards. This has been valuable in distance education (Psotka, 1994). *Desktop* VR is an extension of interactive multimedia involving three-dimensional images and adds to the experience of interactive multimedia without being considered immersive. *Immersive* VR, the focus of this paper, involves a mixture of hardware, software and concepts that allow the user to interact with a three dimensional computer generated "world" (Loeffler & Anderson, 1994).

The specific hardware that currently enables immersive VR includes:

(1) Head Mounted Displays (HMD or 'eyephones') which provide 3D vision of 200 degrees horizontally and 120 degrees vertically (Winn, 1993);

(2) Datagloves which allow the user to interact with the environment by tracking the users motion and giving tactile reinforcement to the visual stimuli in the simulated world and,

(3) Wands or other devices which allow the user to manipulate objects in the virtual world.

The major software required for VR includes high resolution image generators which allow real time rendering so the virtual world is updated as the user acts upon it; and software which allows localized stereo sound and in some cases smell and voice recognition (Psotka, 1994).

In addition, Hedberg & Alexander (1994) include sensory and psychological immersion and active learner participation as defining educational factors of VR. Winn (1995) describes the result of VR's mixture of hardware, software and concepts as a phenomenon known as "cognitive presence", involving a "conviction that the virtual world is a valid, though different, form of reality". This phenomenon has been compared to the "suspension of disbelief" we experience whilst watching a play or movie, but appears to involve less effort on the part of the audience or user, with far more convincing effects.

Virtual Reality and Simulation-Based Training

VR technology is an integrated technology of computer hardware and software that requires the user to be fully immersed into the computer-generated, real-time, and 3D virtual environment as an inside participant to look, listen, manipulate, interact, feel, speak, and even smell if it is possible. It may be a networked or a stand-alone technology.

The characteristics of simulations and VR can heavily overlap or even be synonymous as well as remain distinct, depending on their design and most importantly how they are used in a learning interaction. Simulations-based programs can become VR-based programs with design changes.

According to Thurman & Mattoon (1994), the concept of VR and the wave of research and development accompanying it are creating new form of simulation that may lead to fundamental improvements in simulation-based training. They call this new form of simulation "VR-based simulation". They also indicate that VR is a type of interactive computer-based simulation that is controlled, in part, by the user. In a VR, users perceive a synthetic environment instead of their immediate, physical surroundings, and they are included as part of the simulation (Thurman et. al., 1994). Chiou (1995) supports this claim by defining virtual environment as a simulated environment generated by reality technology in which a learner could behave like an active participant and an active constructor, not like an outside observer.

The main points of VR are full immersion and inside participation. A simulation technology without immersing user as an insider in a simulated environment is not a VR technology. There is much simulation software today that can simulate concrete things and abstract concepts without requiring the user to be inside the simulated world. However, Chiou (1995) considers them neither as VR technology nor as VR software. He clarifies his point by arguing that today's multimedia software on personal computers can simulate and present much information using a variety of forms, but a multimedia system is not an immersive system and definitely not a VR technology.

VR involves a number of interrelated defining and variable concepts that make VR different than other technologies including simulation programs. Thurman & Mattoon (1994) summarize these as integration, interface and verity. They claim that VR is a type of interactive simulation that includes the human user as a necessary component. It is, however, fundamentally different from other interactive simulations, because the user's sense are simultaneously partitioned from the real world and integrated with the synthetic world of VR. Integration of the user in the virtual environment is claimed to be an essential part of VR.

The concept of interface for VR is such that the interface disappears, allowing the user to interact directly with the virtual world. Verity is defined as whether or not the virtual world is "true to life", representing either real world or abstract concepts and relationships. This concept is entirely variable and is one of the most important aspects of VR in education.

For a simulation technology or any other technology to be considered an immersive VR-based technology, immersive input and output devices are necessary. Virtual worlds, like simulations, are programmed environments with which participants can interact in real time. VR goes further than simulations, however, in that virtual worlds can embody arbitrary objects, abstract or concrete, and can be programmed to behave in ways that have no equivalence in the real world (Winn & Bricken, 1992).

Virtual Reality and Learning Theories

The development of models of learning has historically coincided with technological developments, from Behaviorist theory's focus on mechanical control to cognitive theory's focus on computer models of the mind.

Corresponding to the developments of educational theory and its correlation with technological developments, Winn (1993) claims that, in instructional design at least, there have been four generations of development. The first generation was shaped by behaviorist theory. This theory developed traditional drill and practice tutorial instructional design that focuses on imparting objective knowledge or content to the learner. The second and third generations have been informed by cognitive theory's focus on the processes involved in assimilating and encoding information. The second stage of instructional design focuses on the designer and strategies he or she may use to reduce the cognitive load on students thereby facilitating instruction. The third generation focuses on the relationship between the user and the information presented. This stage would include intelligent tutors that attempt to adapt to individual learning styles by responding to the user's interaction with the program. The fourth generation focuses on the constructivist assumption that the learner constructs the knowledge and is characterized by discovery and experimental learning. Winn (1993) suggests that constructivism has outdated all other forms of educational theory.

Perhaps the most well known computer application of constructivism is the LOGO Microworld, developed by Papert, which is based on the concept of constructionism learning. Papert (1993) uses the term "constructionism" to label his favored approach to learning. Constructionism is built on the assumption that children will do best by finding for themselves the specific knowledge they need. The goal is to teach in such a way as to produce the most learning for the least teaching. "Constructionism" differs from "constructivism" in that it looks more closely than other educational -isms at the idea of mental construction. It attaches special significance to the role of constructions in the world as a support for those in the head, thereby becoming less of a purely mentalist doctrine.

Papert's philosophy of learning and his constructionism approach rely on the computer for realization. He imagines a machine he refers to as "The Knowledge Machine" which would allow children a rich exploration of the world. Primitive examples of this Knowledge Machine would include "interactive video", "electronic books" and "virtual reality". It seems that immersive VR is very much close to what Papert has had in mind when discussing the concept of the "Knowledge Machine".

While discussing Microworlds and VR, one may wonder about the differences and similarities between these two technologies. A Microworld has two essential characteristics that may help in such analysis. First, a Microworld embodies the simplest model of a domain that is deemed accurate and appropriate by an expert. Second, it offers an initial point of entry that matches the user's cognitive state to allow interactions to take place.

VR and LOGO are different in terms of interaction. VR represents real experiences in a natural way where the interaction disappears due to the immersive nature of VR. In LOGO, for instance, the keyboard, mouse, or screen comes between the student and the program. In VR there is no interface (Bricken, 1991). Winn & Bricken (1992) argue that interaction with the virtual world is intuitive because students interact with objects in natural ways, by grasping, pointing, etc.

Microworlds can become VRs with design changes. Consider an Algebra Microworld which involves the estimation of distances by using the LOGO command FORWARD to move the turtle from one point to another on the screen with as few commands as possible. In this context the Microworld can be improved into a VR program where the learner can grab the object and move it from one location to another.

Constructivist Learning Theory

According to Papert (1993), constructionism involves two types of construction. First, it asserts that learning is an active process in which people actively construct knowledge from their experience in the world. It also adds the idea that people construct new knowledge with particular effectiveness when they are engaged in constructing personally meaningful products. The one obvious commonality between LOGO Microworld and VR is the fact that both technologies employ constructivism as the most feasible learning theory.

Constructivism is a broad area established on two assumptions. First, that knowledge is constructed through social negotiation, and, second, that reality is to some extent subjective (we all experience the same world but interpret it on the basis of our own knowledge and beliefs) (Winn, 1993). Simply put, constructivists argue for a learner-focused environment in which the learner can explore knowledge domain and construct knowledge of that domain through a combination of collaboration, discussions with their teacher, self-assessment, and reflection.

Constructivism, as noted by Jonassen (1994) proposes that learners construct their own reality, or at least interpret it based on their perceptions of experiences, so an individual's knowledge is a function of one's prior experiences. Furthermore, Jonassen distinguishes between traditional instructional design and constructivist design implying that the traditional instruction focuses on designing instruction that has predictable outcomes and intervenes during instruction to map a predetermined conception of reality onto the student's knowledge. Constructivism, on the other hand, focuses on instruction that fosters the learning process instead of controlling it and it focuses on learning environment rather than instructional sequences

The constructivist paradigm is relatively new, and many issues must be resolved before it can become a sound educational framework. In particular, there are many questions about how educational experiences can be designed that fit with the constructivist epistemology. Jonassen (1994), among others, has identified a set of principles to help with this process. He proposes six principles of constructivist learning environments that are relevant to VR. Those principles are as follows:

- Provide multiple versions of reality, thereby representing the natural complexity of the world.
- Focus on knowledge construction rather than reproduction.
- Present authentic Tasks.
- Foster reflective practice.
- Facilitate context and content-dependent knowledge construction

- Support collaborative constructions of knowledge, rather than encouragement of competition among learners for recognition.

According to Dede (1995), uses of information technology to enhance constructivist learning environments have centered on creating computational tools and virtual representations that students can manipulate. As learners interpret experience to refine their mental models, computational tools that complement human memory and intelligence are made available. In parallel, transitional objects (such as Logo's "turtle") are used to facilitate translating personal experience into abstract symbols (Papert, 1993). Thus, technology-enhanced constructivist learning currently focuses on how representations and applications can mediate interactions among learners and natural or social phenomena.

Dede (1995) argues that, constructivism theory fits very well in a virtual environment. He claims that like Alice walking through the looking glass, learners can immerse themselves in distributed, synthetic environments, becoming learners who vicariously collaborate and learn-by-doing using virtual artifacts to construct knowledge. Interactions between students and phenomena to technological instantiation of learners themselves and reality itself shifts the focus of constructivism from peripherally enhancing how a student interprets a typical interaction with the external world to "magically" shaping the fundamental nature of how learners experience their physical and social context.".

VR Applications in Education

Many researchers and educational practitioners believe that VR technology offers strong benefits that can support education. For some, VR's ability to facilitate constructivist learning activities is the key issue (Rose, 1995). Others focus on the potential to provide alternative forms of learning that can support different types of learners, such as visually oriented learners. Some of the research seeks to locate learning within a very general educational setting. Some studies have investigated the impact of immersion on effectiveness of VR. Overall, most of the studies seek to investigate whether VR is an effective educational technology.

Some of the research on applications of VR for learning involves short term studies and other research is based on longitudinal case studies, while researchers are developing virtual worlds for school use.

An overview of the current research on the effectiveness of VR for its educational uses follows.

Impact of Immersive VR on Learning

Visiting Virtual environments (VE) help students learn content under some circumstances (Byrne, 1996; Dede, 1992, 1995; Rose, 1995). There are three contributing factors: immersion, interaction, and engaging (Winn, 1997).

Immersion: Immersion in a VE makes it possible for students to experience what they are learning about in an entirely new way. VEs can simulate objects and actions that occur in the real world. But in particular, VEs can represent in directly visible forms, concepts and procedures that are intangible and invisible in the real world (Winn, 1997).

According to Bricken (1991), for immersive VR, the interface has ceased to exist altogether in an immersive VR environment. It has been recognized that the removal of interface between computer and user is a necessary condition for immersion in VR. The participant, in a sense, "wears the computer" and is "inside" the data. As a result, the participants can interact with the virtual world, which might be the simulation of some aspect of the real world, as naturally as they do with the real world

Bricken (1991) identified two other changes that take place as a result of immersion that are very important for education. First, the subject-object distinction between students and what they learn disappears. Immersion in a virtual world removes the interface allowing us to cross the subject-object boundary that exists between the machine and us. Second, immersion allows non-symbolic interaction with the world. Immersive VR allows students to interact with the world using what Bricken (1991) calls the "natural semantics" of the world. What Bricken meant by that is that the students can interact with the objects and can actively experience phenomena in the virtual world in ways that are more natural than those normally employed when interacting with computers. For example, in Dede's "Science Space", a student may experience what it is like to be a ball that reacts to forces acting on, and to collisions with another ball, (Dede at al., 1996). The student can learn Newtonian mechanics by becoming and by observing a ball as it responds to student-induced changes in gravity, mass, velocity and elasticity.

Interaction: The second contributing factor to students learning in VEs is the interaction that VEs foster. A study by Byrne (1996) suggested that interaction is a more important facilitator of learning than immersion for some kinds of tasks. Educational technologists have always understood that a student must interact with an environment for learning to occur (Psotka, 1995). Psotka points out that naturalness of interactions with objects in a VE makes interaction much easier and therefore more useful than in other types of environment.

Engaging: The third factor that contributes to VR is that students find VEs entirely engaging (Bricken & Byrne, 1993; Winn, 1997). Winn (1997) explained that part of the reason for this is doubtless the novelty of VR and its association in children's minds with computer and video games. Another reason is the uniqueness of the experience and the empowerment it brings to young students who can control the computer to do their bidding in complex and sophisticated ways. Winn (1997) also believes that it also enables some students to understand concepts and principles that have till now been opaque and baffling which is intrinsically motivating.

It has been argued that immersive VR allow students to learn concepts and to solve problems non-symbolically. Learning in "traditional" classrooms often requires students to master abstract and esoteric symbol systems before they can understand the content (Winn, et. al., 1997). Indeed, the symbol system can be learned subsequently once the concepts have been mastered (Winn, 1993).

Winn (1993) argued that traditional education requires learners to learn complex symbols before concentrating on concepts that are imparted indirectly via educators. Thus many learners may fail because they have problems with the symbolic nature of education, rather than the concepts being communicated. Winn (1993) suggested that non-symbolic interaction, where an individual experiences the world without deliberate reflection and directly, is a possible powerful tool in VR for education, where learners may grapple directly with the concepts.

These claims are also supported by a study conducted by Winn and Bricken (1992). The authors describe an interesting virtual world in which the relationships between objects follow algebraic and arithmetic set of rules. In their proposal, the user can directly manipulate the algebraic elements, and by physical placement the environment can give them feedback on the correctness of the mathematical operations which the user has available to solve the puzzle. Winn & Bricken (1992) argue that it is perfectly possible for students to learn the conceptual basis of Algebra without learning its conventional symbols provided that the learning experience is direct, personal and implicit. If students learning Algebra in immersive VR are strained to symbolize their experiences so that they can communicate it to a teacher or in a test, then, this requirement may get in the way of the natural course of learning. The authors believe that the proposed Algebra virtual world removes the impediments imposed by the traditional text-based symbol system.

Having students construct their own VEs enables them to learn content (Osberg, 1997). Building a VE requires students to construct knowledge of the domain of knowledge the VE embodies. The VE is a projection of students' understanding or mental models, into an entire world of their own creation (Winn, et, al., 1997). Arriving at the understanding necessary to build a VE offers all the advantages of allowing students to construct knowledge for themselves, under guidance, rather than have it fed to them (Dede, 1995; Winn, 1993). Constructing a VE engages those cognitive and perceptual skills that are brought to bear when a student makes any physical construction (Harel & Papert, 1991).

The University of Washington's Human Interface Technology Lab (HITL) is one of the research labs most involved in experimenting with students in real educational settings using current VR technology. The HITL lab makes the following technology available to it researchers. Therefore, the HITL studies reviewed in this paper use the following hardware and software:

Platform: Silicon Graphics interface (SGI) & Division Workstation

Display: Head Mounted Device (HMD)

HMD is device where two miniature display screens, one for each eye, are positioned in front of the users eyes and viewing through optical lenses that serve to magnify images

Special I/O: Speech I/O (specialized sound) & Head devices

Software: Dvise (is the development package that comes with Division's VR workstation.

Hardware: PC & Macintosh (used for student-developed world)

Impact of Immersion, Interaction & Presence

The Wetland project, an HITL project, (Byrne, 1996) serves as an example of a study focusing on the impact of immersion and interactivity on effectiveness of VR-based instruction. In this experimental study Byrne (1996) investigated to whether VR actually is useful in helping students improve their knowledge of chemistry and if so, whether VR's interactivity and immersion were the reasons for this improvement and whether the gains experienced by the students are retained after a period of time.

The main difference among the treatments was the varying degrees of interactivity and immersion. The VR treatment consisted of high interactivity and immersion. The Mac Interactive treatment also consisted of high interactivity, but no immersion (desktop version of VR treatment). The Video treatment and the Mac Run treatment were both treatments of no interactivity and no immersion.

For the VR treatment, 38 high school students, 25 females and 13 males, who were in their second semester of junior level high school chemistry class participated. They had been taught atomic and molecular structure in their first semester of class. They were all novice users of VR. The Video treatment consisted of twenty high school students, 10 females and 10 males, who were in their second semester of junior level high school chemistry. The students for the Mac Interactive treatment were drawn from a similar, but different population than for the VR and video treatments and consisted of 14 students, 7 females and 7 males. The Mac Run students were drawn from the same population as the Mac Interactive group. There were 14 students, 5 females and 9 males. The control group had 7 students, 5 females and 2 males drawn from the same population as the VR and video treatments. The student population for the long-term retention study was a subset of the students who participated in the VR, video, or control treatments. 18 students from the VR treatment, 17 students from the video treatment and 5 students from the control group participated.

Byrne (1996) demonstrated empirically that her VE improved students' conceptual understanding of how atoms are built; though not their recall of facts, relative to other instructional strategies. However, she also found that the key to the success of her VE was the interaction it permitted not the fact that students were immersed in the VE. Students learning from Atom World performed no better than students learning in a non-immersive interactive desktop version of the same program. The interactive desktop program was more effective than a non-interactive, but still immersive version of the VE. Immersion, therefore, may not always be necessary to improve student understanding. This conclusion was due to the fact that students in the VR and Mac Interactive treatments scored well on both of the tests. In most comparisons, their scores were significantly better than the Mac-Run, Video, and Control groups. However, the VR and Mac-Interactive students were not significantly different from each other, which leads to the conclusion that interactivity is the important feature not the immersion. Issues of training, world design, assessment, hardware resolution, and student population were suggested as possible reasons for immersion's lack of significance.

Cell biology serves as another example of a test case to determine the impact of immersion and interaction on effectiveness of VR-based instruction (Gay, 1994). This study was conducted at the Computer Museum in Boston and hence the target audiences for this project were the visitors to the museum. Participants' ages ranged 5 to 50, while their education ranged from high school through graduate school. There were more males than females in this study (percentage not reported). Only 26% had computer related jobs, but 84% used computers in some way at work or at home. None of the participants had much biology experience. The platform used for this study was 486/50 PC based system. The software used in this study was Sense8's WorldToolKit (WTK). The function of the VE was to teach how the different kinds of cells require different organelles in order to perform their different functions. Gay (1994) wanted to test for two characteristics: immersion and interaction. The same information was presented as videotape and as a virtual world and the only difference in information was whether the user was actively involved. This study presented the world in both immersive and the monitor versions to see what differences could be found.

The initial application was designed much like a textbook in that the users first learned about cell requirements and cell function before building a cell and testing its structure. In the first part of the evaluation, the researchers realized that it took users a while to get used to VR interface which distracted them from concentrating on the content. Based on few findings, the cell biology was redesigned. The new design allowed the users an opportunity to get familiar with the interface before any learning began. In addition, it was improved to provide instant feedback their correct usage of the system when building cells. The researcher compared the impact of immersive, desktop, and videotape viewing of the refined application. Generally, the interactive (immersive and desktop) users scored higher on post-testing of symbolic and graphic retention. Desktop users performed slightly better than the immersive users, although researchers suggest that the differing resolution between the HMD used and monitor might account for this difference. However, immersive user did report more enjoyment, and these users stated that they would be more likely to take a free biology class, as compared to users in the other two groups. The users of the fully immersive system showed much less "simulator sickness" than expected. Overall, this study concluded that people learn more from an interactive learning experience than from a passive one. In addition, the results show that immersion did not have significant impact on student' learning.

An evaluative study conducted by Wayne (1997) investigated the sense of "presence". It measured the reactions of students in grades 4-12 to the experience of being immersed in VR. The author sought to assess how learner's ratings of presence in the VE were related to their enjoyment of, navigation in and ability to perform tasks in VEs. Subjects were 1001 elementary, 922 middle school and 949 high school students from a range of social, economic, ethnic backgrounds and geographic areas in the states of Nebraska and Washington. Students attended a presentation on VR, participated in a brainstorming session, and they visited an immersive VE. In the presentation, the students learned how 3-D computing was similar to conventional computing with the exception of the addition of significantly more graphics processing power, a position tracking system, the substitution of the HMD for a flat screen and the use of a wand instead of a mouse. Students used a pointing device called a wand to “fly” from place to place in the VE and could easily move large objects by inserting one’s virtual “hand” in the object while depressing a button on the wand. After the visit they completed a questionnaire featuring a five points rating scale. The questionnaire asked students to rate their enjoyment of the experience, their sense of “presence”, whether they were disoriented, and whether it was easy to move around and interact with objects.

The findings indicate that all students enjoyed their experience of VR. When enjoyment were compared across type of school, the study revealed significant declines from elementary to middle and from middle to high school students (all p’s $< .05$). Also, data collected from Washington public school students indicated that boys enjoyed immersion in VR more than girls did.

The findings also indicate that students experienced a high degree of presence in VR. However, these convictions were significantly more marked in younger than older students did. Students found it easy to identify objects in the VE and did not report any disorientation. Based on the results of the study, Wayne (1997) suggested that VR is a feasible tool to be used in classrooms. He also argued that any potentials for helping student learn the content is likely to arise from the attribute of presence.

Immersive VR vs. Other Instructional Methods

In an evaluative study, Bricken and Byrne (1992)(HITL scientists) evaluated the potential of VR as a learning environment. The context of the study was the Technology Academy, a technology-oriented summer camp for students ages 5-18. The academy offered seven camp sessions. Student activities center on hands-on exploration of new technology. A total of 59 students participated in the study. The average age of the students was 13 years (72% male, homogeneous ethnic origin). None of the students had any experience with or had even heard of VR. The camp allowed seven groups of students, seven weeks to create their own virtual worlds. HITL provided students with Macintosh modeling software package Swivel 3D and several Mac II computers for students to construct their virtual world. Students were provided with a Swivel file containing a "protoworld", which consisted of two basic elements of a virtual world. The first element was the participant's virtual body, represented by a graphic head and hand. The virtual head is the position responsive point-of-view, and the virtual hand is the digital analogue of the participants physical hand, used for gesture commands such as "fly" and "grab". The second element was a ground play extended to the maximum size that the rendering software could handle. On the last day of each session, the students were taken on the 15 minutes ride to HITL at the Washington Technology Center, located at the campus of University of Washington. At HITL, students were able to get inside their worlds using VR interface technology. Bricken and Byrne (1992) used RB2 software on a Macintosh FX rendered by one Iris 320 VGX with a video splitter. First-generation Eyephones were used for viewing and a right-handed datagloves was used for gesture-command activity.

In collecting information on both student response and system usability, the authors used three different information-gathering techniques. They videotaped student activities, elicited student opinions with surveys and collected informal observations from teachers and researchers. The students' worlds were dynamic and interesting and the collaboration was highly cooperative.

The themes of the worlds ranged from Cloudlands to a Moon Colony. For instance, the students who created Cloudlands agreed to disagree on topics so each created his/her own environment on a cloud. These environments ranged from an elaborate house to a sea world. The moon colony project was a more collaborative rendition of the moon in the future, complete with monorail, mountains, futuristic buildings and spacecraft. The students experienced each other's worlds at the end of the seven weeks. In using the worlds the students on the whole had no problems navigating, though one student experienced severe disorientation leading to questions about individual reactions to the virtual environment. Interacting with objects was considerably more difficult, but Bricken and Byrne note that this may be due to the creator's lack of experience. Behaviors such as bending down and reaching out were common, with Bricken and Byrne noting an avenue for research into the implications of VR for kinesthetic learners.

The findings of this study indicated that the students were fascinated by their experience and entering virtual world. The students were motivated to achieve functional competence in the skills to design and model objects, demonstrated a willingness to focus significant effort toward finished product, and expressed strong satisfaction with their accomplishments. The study also reports that students demonstrated rapid comprehension of complex concepts and skills. They learned computer graphic concepts, 3-D modeling techniques, and world design approaches. Overall, Bricken and Byrne found VR in this study to be a significantly compelling creative learning environment.

The most relevant work on the issue of how learning is mediated through the use of VR to date is that of Dede, et. al.(1996b) on the ScienceSpace project at George Mason University. Since February 1994, the project team has worked collaboratively to build "ScienceSpace," a collection of virtual worlds designed to aid students in mastering challenging concepts in science. ScienceSpace now consists of three worlds-NewtonWorld, MaxwellWorld, and PaulingWorld-in various states of maturity.

NewtonWorld provides an environment for investigating the kinematics and dynamics of one-dimensional motion. MaxwellWorld supports the exploration of Electrostatics, leading up to the concept of Gauss' Law. PaulingWorld, the most recent addition, enables the study of molecular structures via a variety of representations.

All three worlds have been built using a polygonal geometry. Colored, shaded polygons and textures are used to produce detailed objects. These objects are linked together and given behaviors through the use of NASA-developed software that defines the virtual worlds and connects them to underlying physical simulations. Interactivity is achieved through the linkage of external devices (e.g., a head-mounted display) using this same software. Finally, graphics rendering, collision detection, and lighting models are provided by other NASA-developed software. The key hardware items used are a high-performance graphics workstation with two video output channels; a color, stereoscopic head-mounted display (HMD); a high-quality sound system; a magnetic tracking system for the head and both hands; and, in some cases, a haptic display. Interaction in these worlds is principally carried out with a three-dimensional mouse. The software is called Custom (Dede, et. al., 1996b). Haptic feedback has been employed in NewtonWorld and MaxwellWorld, in evaluating the impact of multi-sensory feedback on learning effectiveness. The haptic feedback was provided by two different haptic vests, both of which operate by converting sound wave to vibrations.

Dede, et. al. (1996b) evaluated MaxwellWorld as a tool for (1) remediating misconceptions about electric fields and (2) teaching abstract concepts with which students are unfamiliar. During the sessions, they administered one to three lessons centering on the construction and exploration of electric fields (electric force, superposition, test charges, and field lines), learning experiences about electric potential (potential and kinetic energy, potential difference, work, and potential vs. force), and the concept of flux through surfaces (open and closed).

The authors claim that although these evaluations are still underway, they report preliminary findings based on 14 high school students (and four college students) who have participated in the evaluations thus far. Each session lasted for approximately two hours. Students were scheduled on consecutive days for the first two sessions, while the third session was conducted approximately two weeks later; thus providing a measure of the retention over time.

The results of the study indicate that all of the students who were post-tested enjoyed learning about electric fields in MaxwellWorld. When asked about their general reactions to MaxwellWorld, a majority of the students commented that they felt it was a more effective way to learn about electric fields than either textbooks or lectures. Students cited the 3-D representations, the interactivity, the ability to navigate to multiple perspectives, and the use of color as characteristics of MaxwellWorld that were important to their learning experience. Pre- and post-lesson evaluations showed that students developed a more in-depth understanding of the distribution of forces in an electric field, as well as representations such as test charge traces and field lines.

The authors also report significant individual differences in the students' abilities to work in the 3-D environment and with 3-D controls, as well as their susceptibility to symptoms of simulator sickness (eyestrain, headaches, dizziness, and nausea). While some students learned to use the menus, manipulate objects, and navigate very rapidly, others required guidance throughout the sessions. Most students experienced nothing more than slight eyestrain; however, two students experienced moderate dizziness and slight nausea during the first session, and, consequently, did not return for the second session. No student complained of any symptoms during the first 30-45 minutes of the lesson, reinforcing our strategy of using multiple, short learning experiences.

Dede, et. al. (1996b), conducted formative learnability evaluations on NewtonWorld, focusing on both the importance of the multisensory experience and reference frame usage in learning. Thirty high school students with at least one year of high school physics participated in this study. Each trial required 2 1/2 to 3 hours; learning tasks in the HMD required 1 to 1-1/4 hours. During the sessions, students thought aloud as they performed learning tasks that focused on relationships among force, mass, velocity, momentum, acceleration, and energy during and between collisions. For each task, students began by predicting what the relationships or behaviors would be, then experienced them, and finally assessed their predictions based on what they observed. To assess the utility of the multisensory experience, the authors formed three groups of subjects differentiated by controlling the visual, tactile, and auditory cues that students received while performing learning tasks: (1) visual cues only; (2) visual and auditory cues; or (3) visual, auditory, and haptic cues.

The authors' observations during the sessions, students' predictions and comments, usability questionnaires, interview feedback, and pre- and post-test knowledge assessments were used to determine whether NewtonWorld aided students in better understanding relationships among force, motion, velocity, and energy. Most students found the activities interesting and enjoyed their learning experience. Additionally, many users stated that they felt NewtonWorld provided a good way to explore physics concepts. When asked to list the features they liked most, almost all students cited the ability to beam to various cameras and to navigate in the movable camera.

Students did appear to be more engaged in activities when more multisensory cues were provided. In fact, students receiving sound or sound plus haptic cues rated NewtonWorld as easier to use and the egocentric reference frame as more meaningful than those receiving visual cues only. For example, students who received haptic cues in addition to sound and visual cues performed slightly better than students in other groups on questions relating to velocity and acceleration. Additionally, lesson administrators observed that students receiving haptic and sound cues were more attentive to these factors than students without these cues.

Overall, the students found the environment easy to use. The authors argue that the analysis of the learnability data suggests that younger users might gain more from virtual experiences in sensory immersive Newtonian environments than do high school students. The findings MaxwellWorld and NewtonWorld studies reported here (Dede, et.

al. 1996b) demonstrate that students find virtual worlds attractive learning environments. In some topical areas, especially abstract concepts in electrostatics, students did learn from their experiences.

In another study, Salzman, et. al. (1999) designed an evaluation to compare the learning, learning experience, and interaction experience in MaxwellWorld (MW) to those of a highly regarded and widely used 2D learning environment, EM Field (EMF), while tightly controlling the learning activities and instructional content of the lessons. Lessons were designed to provide the same content and learning activities using each of the application, focusing on concepts pertaining to the distribution of force and energy in electric fields.

Stage one of the study compared MW and EMF on the extent to which representational aspects of these environments influenced learning, learning experience, and interaction outcomes. In the stage two of the study, MW's full range of capabilities (such as multisensory input) were utilized to ascertain the value these affordances added to the learning experience. Fourteen high school students completed the lessons in both MW and EMF. Seven of students came back after 5 months for completing the stage two of the study. The authors examined pre- and post lesson understanding of each of the groups. They also assessed retention for those students that returned to stage two. They gathered information about individual differences such as domain experience, computer and gaming experience, and motion sickness history. The also examined whether learning experience (motivation and meaningfulness of the representation) and interaction experience (sickness and usability) differed between the groups and whether they predicted learning outcomes. At the end of the first stage, both groups demonstrated significantly improved conceptual understanding, with MaxwellWorld students better able to define concepts than students who used EMF. Also, MaxwellWorld students performed better in demonstrating concepts in 3D, were able to predict how change to a source would affect the electric field, and could recognize symmetries in the field. Student ratings indicated that they felt significantly more motivated by MW than EMF ($F(1,12) = 7.66$). On the scale from –3 to +3, mean ratings (and standard deviation) were 2.03 (.29) and 1.11 (.82) respectfully. Neither motivation nor meaningfulness of the representation significantly predicted learning outcomes. The findings also report that the more time the participants spent using computers, the higher usability was rated.

In the second stage of evaluation, a subset of students was given an additional lesson in MaxwellWorld, this time supported by auditory and haptic cues. The results showed that students gained a significantly better understanding of concepts, and improved their ability in demonstrating these concepts in 2D and 3D representation (all F-tests were significant at $p < .05$). Students learned more from the visual and multisensory representations used in the lesson. Mean motivation was reported the same as stage one. Overall, these results suggest that an immersive 3D multisensory world can aid student in developing appropriate mental models better than 2D representations. In stage two, the enhancement of visual representations with multisensory cues appeared to facilitate learning, especially for students who had trouble grasping the concepts.

Salzman, et. al.(1999) report the following findings based on all their studies discussed above:

- Evaluation outcomes indicate that VR’s features affect not only learning, but the quality of the interaction and learning experiences

- Outcomes show that 3-D immersive representations can be motivating and can support learning
- VR's features sometimes support the learning of one concept, but hinder the learning of another
- Learning experience is affected by VR's features
- The success or failure of VR learning environments in practice depends on the web of relations among VR's features, the concepts to be learned, learner characteristics, the learning experience, the interaction experience and more informed design.

Identifying VR as a full-immersion technology with head mounted display, data glove, 3-D earphones and tracking equipment, Chiou (1995) felt there is potential for VR as a learning medium. The author believes that constructivism rationale can be applied to VR and that computer-based tools need to be under the learner's control. He argues that we can expect the growth of VR to parallel that of multimedia in impacting education. Finally, he calls for specific design models for VR-based learning.

Merickel (1992) conducted an experiment, Creative Technology Project, with 23 children between the age of 8 and 11 who were enrolled in an elementary summer school program in Navota, California. Two different computer apparatuses were used: computer workstation and VR system developed by Autodesk Inc. The abilities under investigation were mental imagery, spatial relation, displacement and transformation, creativity and spatially problem solving. The hypothesis was that children's cognitive abilities could be enhances by having them develop, displace, transform, and interact with 2D and 3D computer generated models. Although children had some difficulties in using the peripheral devices, they had become quite proficient in the system by the end of the study. The results of the project showed that displacement, transformation, visualizing, and mentally manipulating 2D objects were significantly related to spatially related problem solving abilities of children (R=68, F= 8.05, ndf = 1.20, p = .00). Although creative thinking was found not to be significantly related to spatially problem-solving abilities, the relationship between the two is uncertain. The author concluded that VR is highly promising and deserves extensive development as an instructional tool.

Andolsek (1995) suggests that since virtual worlds are totally engaging, they immerse the student entirely, both cognitively and affectively. Passivity becomes impossible. Virtual environments may have great potential in terms of increasing the learner motivation. If learning is made more interesting and fun, students may remain engaged in an activity for longer period of time. Bricken & Byrne (1992) claim that since VR places learners in a 3D visual and auditory environment, the sensation the learner receives are pervasive and convincing and indeed engaging and motivating. However, the challenge would be, how to increase the learner motivation to stay engaged in a virtual environment. This is where the design and usability issues become very important factors in a virtual environment. If VR can provide such potential to actively engage students in VE and motivate the learner to stay engaged, then it would provide solutions to so many unanswered questions in education in terms of learner motivation and learning.

Learner Characteristics & VR Learning

Due to the fact that VR is a new technology, its use as an educational tool is quite new with very little empirical research related to learner characteristics. Various studies have addressed the fact that it is important to investigate whether factors of gender, race, or student experience impact their interaction with and enjoyment of VR. Dede (1996a) identified several learner characteristics as important factors: gender, domain experience, spatial ability, computer experience, motion sickness history, and immersive tendencies.

Gender, domain experience, and spatial ability are important factors because they might influence a person's aptitude for mastering abstract science concepts (Dillon, 1985; Dillon & Schmeck, 1983). Spatial ability may be particularly important in influencing how effectively students use the information provided by VR's features (Egan & Gomez, 1985; Norman, 1995). Many researchers have implicated that spatial ability as one of the strongest predictors of performance in math and science (Halpern, 1992). Spatial ability, along with computer experience and motion sickness history, might also affect the interaction experience (Dede et. al. 1999). In their work, Dede & colleagues (1999), found that computer experience can be predictive of how students rate the usability of the learning environment. Other researchers have found that there is a strong correlation between spatial ability and computer-based performance (Egan, 1988; Gomez, Egan, & Bowers, 1986). Immersive tendencies may be useful for explaining how immersed a student will become in the VR learning environment (Singer & Baily, 1994).

In one exploratory study Winn & few other HITL's researchers (1997) investigated to see whether the unique experiences of building and visiting VEs would be more useful to some students than others. They examined the extent to which students' general ability, and secondary school students' spatial reasoning ability and spatial orientation ability predicted performance after learning by building and visiting VEs and after learning the same content in more traditional ways.

The subjects for this study were 365 students from grades 4 to 12 took part in the world-building project. Students took post-tests over the content they had been studying.

Since each group of students built a different VE, there was a different post-test for each group. Students also completed a questionnaire. This consisted of 24 five-point scale questions in a number of areas. The questionnaire included questions concerning enjoyment, the sense of` "presence" in the VE (the extent to which students felt they were really in the VE and not in the classroom), and potential impediments to learning such as difficulty seeing and moving around in the VE and tendency to nausea. Students who did not build worlds and who were in a "traditional" class answered an eight-item subset of these questions that were concerned with the VR experience not with building a world.

The results of posttest scores involving "World-building" and "Traditional" groups crossing with high and low ability show no main effect for group. However, the interaction of group with high ability was significant, $F(1,44)=2.91$, $p<.10$. Low-ability students who did world-building (M=68.62%, SD=20.75) significantly outperformed those studying in the traditional way (M=42.55%, SD=26.28), $F(1,44)=8.67$, $p<.01$. For high-ability students, there was no difference in performance (MVR=60.16%, SD=18.75, MTraditional=60.89%, SD=19.36).

Students were also blocked on their spatial ability and spatial visualization scores. No significant main effects or interactions were found for either measure with content posttest performance as the dependent variable.

The authors also reported that that high general ability students reported making paper drawings and 3D models of objects before modeling them on the computer more than low ability students, $t(41)=1.82$, $p<.10$. In addition, high spatial reasoning students enjoyed visiting their world and experienced higher levels of presence than low spatial students, $t(22)=2.47$, $p<.05$. Results also showed that high spatial reasoning students were also likely to feel less nausea and less dizziness than low spatial students, $t(22)=1.74$, $p<.10$. Furthermore, students with higher spatial visualization scores collaborated more with other students with low spatial visualization scores, $t(22)=1.72$, $p<.10$.

The authors also conducted a two-way ANOVA involving two levels of gender and two levels of spatial reasoning ability was performed on presence scores. For gender, they reported $F(1,53) = 6.53$, $p<.05$. For spatial ability, they reported $F(1,53) = 5.58$, $p < .05$. For the interaction of gender with spatial ability, they reported $F(1,53) = 5.51$, $p < .05$. Spatial reasoning ability did not affect presence ratings for boys, (MLow Spatial = 7.47, sd = 1.26, MHigh Spatial = 7.47, sd = 1.93). However, low spatial girls reported lower presence than high spatial girls, (MLow Spatial = 5.14, sd = 1.96, MHigh Spatial = 7.38, sd = 1.41, $t(20) = 2.82$, $p < .01$).

Winn, et. al. (1997) report that in general the world-building activity improved the posttest performance of low ability students who built worlds when compared to those learning in a traditional manner. This implies that the collection of innovative learning activities afforded by world building helped students understand the material who do not have high general ability as measured using a traditional test. The lack of difference between high ability students in both groups simply reconfirms that brighter students can learn from a variety of approaches and therefore, for them, the innovative nature of the world-building strategy had no effect.

Girls with low spatial reasoning ability reported experiencing less presence than girls with high spatial reasoning ability. This difference was not found for boys, who reported higher levels of presence than girls. It is possible that boys have different ways from girls of becoming engaged in a VE. Maybe they have more exposure to computer games and have developed better skills for manipulating the interface than girls. Maybe they are more easily fooled into believing a VE is real than girls.

The Virtual Reality Roving Vehicles (VRRV) (Rose, 1995) is another project by HITL scientists which takes VR technology into public elementary, junior high and high schools and puts it in the hands of students and teachers. The goal of the project is to evaluate VR as a tool for students to develop broad-based abilities including, but not limited to: problem solving, building mental models, and developing effective meta-cognitive strategies and visualization. The VRRV is applying a `constructivist' approach to instruction that puts each student in charge of his/her own process of learning.

In November 1994, the VRRV undertook a month-long world building project with 120 junior high school students at Kellogg Middle School in Shoreline, Washington. According to Rose (1996), the purpose of this VRRV project was to look at the issue of gender. The Kellogg Project integrated the building of virtual worlds into a specially designed curriculum about Wetlands ecology. Four classes of thirty students participated; each one was randomly assigned to focus on one of the wetlands life cycles: water, carbon, energy and nitrogen. Students learned the fundamentals of their respective cycle according to a constructivist curriculum designed by Kellogg teachers. Each class was then divided into three working groups who each planned and designed a virtual world to express their understanding of the wetlands cycle they studied (Rose, 1995). The contributions of the three working groups in each class were brought together and a single virtual world was constructed for each of the four life cycles. The virtual wetland worlds were populated with plants, animals, objects and landscapes which students created on desktop computers using 3D modeling software. As the final step of the learning process, students put on a VR head mounted display and experienced two of the wetlands worlds, their own plus one other.

At the elementary level, self-reports on the amount of learning that took place indicated that boys benefited more than girls from world building activities. At the secondary level, boy reported more enjoyment from the use of VR than did girls. With respect to general abilities, the VRRV data indicated that students performed equally well. However, students with high spatial ability reported more enjoyment, and feeling of presence than did those with low spatial ability.

Conclusion

This paper has reviewed the uses of VR in education and its implication for learning. It is important to keep in mind that VR technology and its application to education is still evolving. The studies described in this paper include the results of one-time uses of virtual world by particular group of students, with only a few results reported on the long-term use of the VR technology. As a result, the conclusions are not generalizable to a larger population of students and reflect only the findings of current studies. Hopefully they will serve to guide further research on the use of VR in education. The summary of findings are addressed according to the questions initially raised in this paper. The remainder of this section returns to the questions raised in this paper to provide a summery of the findings.

- Do learning in virtual learning environment offer advantages over more traditional methodologies?
- What implications for learning do immersive virtual world offer?
- Which learning rationale is the most suitable for VR environments?
- How does student effectiveness of virtual world compares with other instructional practices?
- What is the impact of learner characteristics (e.g. age, gender, race, or previous experience) on learning in VR? What types of learners benefit from VR?

Summary

(1) Do learning in virtual learning environment offer advantages over more traditional methodologies?

Unique capabilities of VR technology include allowing students to see the effects of changing physical law, observe events at an atomic scale, visualize abstract concepts, and visit environments and interact with events that distance, time, or safety factor normally preclude. Studies show that these unique capabilities of VR technology allow virtual worlds to support a wide range of types of experiential, conceptual, and discovery learning that is not otherwise available.

The literature review reveals the rudimental state of VR systems and to a certain extent the subsequent difficulties in applying this technology to education. However, existing data support that VR offers significant, positive support for education. They indicate sufficient potential value to justify continuing research and development activities particularly in learning theories and constructivism, and increasing practical evaluations of technology uses. Such work needs to occur hand-in-hand with research into learning theories, constructivism, in particular.

(2) What implications for learning do immersive virtual world offer?

Studies showed mixed findings for the impact of immersion on student learning. Byrne (1996) as well as Gay (1994) concluded that interactivity is an important feature but not immersion. Issues of training, world design, assessment, hardware resolution, and student population were suggested as possible reasons for immersion's lack of significance. In the case of both studies, the failure of positive findings in terms of immersion might be due to one of the following factors:

- The lack of student familiarity with the VR interface
- An insufficient number of experimental trail
- Differences in the number of trail for each treatment, and/or
- Unreliability of one of the measures used.

Other research findings indicate that the value of VR for education lies within its ability to provide immersion of the user in either realistic or novel and abstract environments. The immersion allows the user to experience, interact with and discover digital knowledge first hand while the manipulation of the verity of the virtual world allows the user to make visual or kinesthetic relationships to help understanding of the real world or concepts related to it.

Although, Byrne’s and Gay's findings show uncertain learning benefits for immersion, it is important to note that the participants in the immersive conditions in all of the studies (including Byrne’s) presented in this paper expressed more enjoyment and motivation to learn than those exposed to the non-immersive conditions.

Preliminary research at the Human Interface Technology Laboratory at the University of Washington (Bricken (1991); Bricken and Byrne, 1993; Winn (1999); Winn (1993); Winn (1995); Rose (1995); Byrne (1996) and elsewhere (Dede, C., Loftin, R.B., Salzman, M.C., Calhoun, C., Hoblit, J. & Regian, W.(1994); Dede, C., Salzman, M.C. & Loftin, R.B., Chen, J.(1999)) gives us an intuitive sense that VR could be highly useful to promote skills and knowledge which students can apply across many domains. The interactive and immersive qualities of VR suggest the potential for an entirely new form of experiential learning.

In one study, the researchers (Salzman, M.C., Dede, C., & Loftin, R.B., Chen, J., 1999) concluded that:

- VR’s features affect not only learning, but the quality of the interaction and learning experiences,
- Three-dimensional immersive representations can be motivating and can support learning,
- VR’s features sometimes support the learning of one concept, but hinder the learning of another
- VR's features affect Learning experience

Overall, all of the studies demonstrated that the technology known as VR is highly promising and deserves extensive development as an instructional tool.

(3) Which learning rational is the most suitable for VR environments?

Almost all of the studies suggested that constructivism provides the best theory on which to develop educational applications of VR. Research findings indicate that a way to create learning experience and transference is to allow users to construct and experience their own abstract worlds.

Studies also suggested that having students construct their own VEs enable them to learn content. Building a VE requires students to construct knowledge of the domain of knowledge the VE embodies. Arriving at the understanding necessary to build a VE is believed to offer all the advantages of allowing students to construct knowledge for themselves, under guidance, rather than have it fed to them (Dede, 1995; Winn, 1993; Osberg, 1997; Chiou, 1995).

The studies reported here provide initial findings that are suggestive of suitability of constructivism in VR instruction and the majority of uses of the technology have included aspects of constructivist learning. However, it is impossible to know whether positive results are due to the use of this learning method, the use of VR, or a combination of the two.

(4) How does student effectiveness of virtual world compares with other instructional practices?

The studies that have addressed this question were constructed in very different areas of curricula, with students in different age groups. However, the literature shows that VR is a powerful tool for education and that it offers tools for increased student participation. Studies indicated that classroom activities may use VR tools for hands-on learning, group projects and discussions, field trips, and concept visualization. Traditional teaching involves text, oral and screen-based presentations which may not use a human's full capacity to learn.

The findings suggest that immersive VR can furnish experiences that are designed to help students learn material. For instance, in an Algebra virtual environment, (Winn & Bricken, 1992) in which instead of learning the symbols in Algebra, students could explore the objects, learn the concepts and construct their own knowledge. This study suggests that VRs promote the best and probably only strategy that allows student to learn from non-symbolic experience. Great many students fail in school because they do not master the symbol systems of the disciplines they study, although they are perfectly capable of mastering the concepts that lie at the heart of the discipline. VR provides a route to success for children who might otherwise fail in our education system as it is currently constructed (Win 1993; Winn & Bricken, 1992).

In most of the studies, students reported a positive attitude and enjoyed learning through immersive virtual environments. Winn et. al., (1997) found that in general the world-building activity improved the posttest performance of low ability students who built worlds when compared to those learning in a traditional manner. In the MaxwellWorld project (Dede, et. al., 1996b), the students felt that it was more effective way to learn through VR than either textbooks or lectures.

In general, studies show that benefits of VR include the ability to incorporate practices such a providing multiple representations and placing some instruction under learner's control. Also, students constructed their own knowledge in VR. Provided in this paper are initial findings that suggest that these capabilities have value.

(5) What is impact of learner characteristics (e.g. age, gender, race, or previous experience) on learning in VR? What types of learners benefit from VR?

According to Salzman, Dede, et. al. (1999) the success or failure of VR learning environments in practice depends on the web of relations among VR's features, the concepts to be learned, learner characteristics, the learning experience, the interaction experience and more informed design. However, very few empirical studies look into the issue of learner characteristics in VR. Only few studies investigated the issue and gender and reported that boys enjoyed the use of VR more than did girls (Dede, et al. (1996a,b); Win et al. 1997; Rose (1995), Byrne (1996); Wayne (1997); Bricken & Byrne (1992)). These studies showed that students performed well in using VR and enjoyed their experience. Winn (1995) reported few significant differences in terms of race or gender.

Girls with low spatial reasoning ability reported experiencing less presence than girls with high spatial reasoning ability. This difference was not found for boys, who reported higher levels of presence than girls (Winn et. al., 1997).

The Wetland study (Bricken & Byrne, 1992) reported that as students get older, they enjoy their experience, but slightly less than younger students. Elementary students enjoyed themselves the most, followed by middle school students. High school students seemed slightly more jaded about the technology, or at least inclined to be more cool in their response to their experience. In addition, boys reported experiencing a greater sense of immersion than did girls.

VRRV (Rose, 1995) indicated a worrisome influence of gender, in at the elementary level, self-reports on the amount of learning that took place indicated that boys benefited more than girls from world building activities. At the secondary level, boy reported more enjoyment from the use of VR than did girls. With respect to general abilities, students performed equally well. However, students with high spatial ability reported more enjoyment, and feeling of presence than did those with low spatial ability.

It is possible that boys have different ways of becoming engaged in a VE. Maybe they have more exposure to computer games and have developed better skills for manipulating the interface than girls.

Concluding Remarks

It is important that researchers begin to identify and solve the issues concerning VR now so that it can be used to its best advantage by all students in the future. As the technology matures, VR will have the potential to become an extremely powerful medium. However, as with every technology, it must be remembered that VR is a tool to be used as a medium with other methods of instruction.

Most of the studies presented in this paper are on going. Therefore, the results may change as the studies advance. These studies tend to be evaluative and although have shown very encouraging results, do not provide quantified data to show, for instance, how well VR works in comparison to other techniques.

Numerous factors unrelated to the VR technology itself will undoubtedly have a crucial impact on students' learning achievement. These factors include differences in individual classroom environments, student characteristics such as personal history or attitudes towards computers, teachers' attitudes and background in technology, and an assortment of social, economic and political variables related to schools, education and technology. A comprehensive assessment of VR technology must take account of how these external factors contribute to the overall context in which VR is applied.

The future research must take closer look at the possible influence of gender and other student characteristics on the effectiveness of different types of educational uses of VR technology. As shown in this paper, there are very few studies that investigate learner characteristics. This is, however, justifiable due to the fact that the application of VR in education is a very new phenomenon. Researchers need to, for instance, investigate whether different groups of students require different types of introduction to VR technology or prior training in skills such as spatial skills. Investigation of these issues is needed to ensure effective use of VR technology.

There are many unanswered questions related to the impact of VR on learning that need to be addressed. Presence is clearly a key to learning in a VE and is related to spatial reasoning ability (Wayne, 1997). Gender is a factor here and its precise role must be determined.

Another important question that needs to be investigated is whether the effective uses of technology change the teacher's role in the classroom. The fact that it is difficult for teachers to monitor student's moment-by-moment activities can present challenges for lesson administration. Also, current applications do not provide teachers with assistance for assessing a student's learning or recognizing particular problems a student may have with the material. The integration of intelligent tutors into educational VR applications seems a logical next step that should help to resolve some of these problems. Given the sophistication of some of the current VR application, it is surprising that no evidence of such integration was found.

Research should investigate student and teacher reactions to the use of VR technology. Few of the studies reported student enjoyment and motivation. But does this enjoyment and increased motivation last? There is no data to answer this question, although the ScienceSpace researchers felt that learner motivation will remain high, even when the novelty factor of VR technology has worn off.

The issue of multi-sensory immersion also needs to be further investigated. In the long run, research on immersion may produce a deeper understanding of the nature of human learning. In the same context, an investigation of the interplay among VR and other factors such as the concepts to be learned, learner characteristics, the learning experience, and the interaction experience is needed. By understanding how these factors work together to shape learning, we may be able to target learning and visualization problems and to maximize the benefits of immersive VR. For example, in MaxwellWorld project, if the researchers had not concerned with these factors, they might have missed several potential findings and would have been less able to identify the benefits of 3-D immersion for learning.

As the technology for building and learning in VE advances both the quality of the VE and the ease of working in it, more carefully controlled studies will be possible.

Then researchers will be in a position to conduct studies of precisely which features of VEs facilitate the learning of what kinds of content for which students.

By making VR tools and environments available to educators, we may discover more about the very process of learning. By participating in the development of VR, educators can guide the growth of this technology, and perhaps influence the course of educational change.

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