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**DIFFERENTIATION OF THE CAUSAL CHARACTERISTICS
AND INFLUENCES OF VIRTUAL REALITY
AND THE EFFECTS ON LEARNING AT A SCIENCE EXHIBIT**

by

Arlene de Strulle

A dissertation submitted to the faculty of
San Diego State University and the University of San Diego
in partial fulfillment of the requirements for the degree of
Doctor of Education

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July, 2004

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Abstract

Within the context of the informal science center, exhibits are the main interface for public learning. Essential to the success of a science center is how well exhibits model effective strategies for learning. Virtual Reality (VR) technology with its flexible, adaptive, multimedia, and immersive-learning capabilities is emerging for use by science centers in exhibits; however, research on learning in virtual environments at exhibits is scarce. To support the future development of VR science exhibits it is critical to investigate VR's pedagogical value and effects on science learning.

Research investigated the *Smoke & Mirrors* VR exhibit at the Reuben H. Fleet Science Center in San Diego, California. Inquiry focused on the interplay between elements of the exhibit's design, assessing the separate and interactive effects of visual imagery, moving images, sound, narration, and interactive tools to differentiate the causal characteristics and influences that enhanced and detracted from learning.

Case study methodology was employed utilizing visitor observations and interviews with 14 participants. Findings indicated that realistic visual elements with text were the primary sources of content learning; however, positive results were limited to only a few participants. High cognitive load due to interactive tools; instructional design; and movement of visual images were found to be significant detracting characteristics of participant learning. Other characteristics and influences of VR were also found that directly effected learning.

Research results will inform the forthcoming design of a new VR exhibit at the Reuben H. Fleet Science Center and to the design and development of future VR exhibits

at informal science centers. A prior brief mixed-methods evaluation of *Smoke & Mirrors* was conducted in 2003, contributing background to the study and its future implications and strategies.

The dissertation is dedicated to
Miriam Altneu de Strulle,
my mother and best friend,
who inspired my passion for learning, inquiry, and discovery,
who is always ready an adventure,
and whose unceasing question:
“Aren’t you finished, yet?”
can now finally be affirmatively answered.

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Immense appreciation to Lynne Kennedy, Deputy Executive Director of Education and Exhibits at the Reuben H. Fleet Science Center, for accommodating and embracing all aspects of the research so graciously, and for the Fleet Science Center's commitment to the advancement of science education research, and innovative leadership in evolving Virtual Reality exhibits.

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I share the accomplishment of the doctoral degree with both William T. Golden and Joan Friedson. This achievement would not have happened without each of their personal commitment to my success, and their relentless insistence that I remain true to myself.

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DIFFERENTIATION OF
THE CAUSAL CHARACTERISTICS AND INFLUENCES OF VIRTUAL REALITY
AND THE EFFECTS ON LEARNING AT A SCIENCE EXHIBIT

Chapter One: Introduction

Technology is playing an increasingly essential role in our society, affecting almost every aspect our lives. Consider the invention of the automobile, electricity, computers, and space travel, as examples of the complexity of technology, and its impact on how we live. Not only is technology affecting us through its afforded conveniences, it is also changing and shaping our conceptual and scientific understanding of the world. Advances in visual technologies used for science and medical research are infusing our world with the most extraordinary and elegant insights into human molecular biology, and Earth's systems and processes from sea and space exploration. The visualization of the double stranded alpha helix structure of DNA is an example of discoveries made through visual technology. This is of great significance, for science education demands complex understanding from scientists, as well as students. Visualization of the most simplistic of structures in three dimensions can promote comprehension of the most complex. Above any other evolving technology, the emergence of visualization technology appears to have the highest potential for altering how perceive and comprehend our world. Of the visual technologies and applications to emerge over the last two decades, Virtual Reality (VR) is the most promising (Newby, 1993). As a technology with many forms and applications, VR has the capability of *virtually* bringing all aspects of the sciences, from sea to solar system, in visual form, to almost any technologically viable location, including informal science centers and schools.

However, in the midst of what might be considered a second Renaissance in science research and discovery, there still exists a profound lack of effective science teaching and learning in schools, causing a devastating effect on student performance in science, as well as on our nation's future leadership in science and technology. In part, this is due to the relentless advances occurring in science, based upon technology innovation. Our perception of the world through better technological tools is constantly shifting our paradigm of understanding and is doing so at such an accelerated rate that scientists, as well as schools, can hardly keep up with the pace. In addition, there is usually a long interlude between technological innovation and its application in education. As a result, science concepts children learn will become outdated and inapplicable by their adulthood.

Senator John Glenn, Chair of the National Commission on Mathematics and Science Teaching for the 21st Century, concluded in his landmark report on science education, *Before It's Too Late: A Report to the Nation* (1990), that our future as individuals, as a nation, and as a global society, unequivocally depends on our nation's response to improving and innovating science education. For over a decade, subsequent to the Glenn report, the United States has initiated studies to comprehensively investigate improvement of science learning. Results of recent assessments echo a similarly dismal message with a resounding appeal to improve science teaching and learning in America. Trends in International Mathematics and Science Study (TIMSS), the largest and most comprehensive international assessment of student achievement, assessed and offered solutions to the issues surrounding low student performance in science.

Studies by TIMSS (1995a; 1999b), ranked American students among the lowest in the world. Out of 41 countries participating in the study, American eighth grade

students were ranked 28th in mathematics, and 17th in science. The National Action Council for Minorities in Engineering (2002) mention in their public materials that more than half of all American minority students indicate they plan to drop mathematics and science courses when schools allow them to make their own course selections that do not require science.

Causes of poor student performance in science include inadequate preparation and exposure to modern science concepts; absence of robust science curriculum; and lack of relevant learning opportunities, in or outside of the classroom. Despite decades of research on teaching and learning, science education remains essentially the same as it was. Almost all major science curriculum developments of the 1960s and early 1970s promote hands-on activities as the most effective form of learning (Hodson, 1990). Teachers, administrators, publishers, and trade books all refer to the importance of hands-on activities in science instruction (Flick, 1993). Research in cognitive psychology supports conclusions that hands-on, experiential activities not only promote learning, they expand upon the innately inquisitive and exploratory nature of children. After decades of research, approaches to learning are not being designed to capitalize upon the innate curiosity and abilities of children (Shapley & Luttrell, 1993), science is still being taught in classrooms essentially the way it was generations ago (Bransford, Brown, & Cocking, 2000). In addition to ineffective methods, teachers are using inaccurate and outdated science textbooks to inform new generations of students. How will these students be prepared to lead this country in the future in scientific innovation, as other countries commit major funding for science education.

Inadequate professional development of science teachers; reduced funding for

relevant science learning opportunities, especially in the middle and high school years; and an unclear national strategy for science education are contributing to the unraveling of science education at all levels. As a result, our nation's students are left scientifically illiterate, uninspired, and disinterested in pursuing science professions in a national and world economy that is increasing, exponentially, in its dependence on science and technology.

Science educators have a daunting task meeting the challenge of improving science education at their school. With stringent budget cuts, outdated science textbooks, and the need for professional development in science. Although science education has its roots in experiential learning (Dewey, 1939; Kappa Pi Lecture Series, 1997), experiential learning is not often taught in professional credentialing programs and is often sacrificed in classrooms to address standardized testing requirements. As a result, teachers are looking for assistance beyond the parameters of their schools for relevant and contextually rich science teaching and learning experiences.

Informal Science Comes of Age

Experience and research data, have elevated the value of informal science education methods previously considered pseudo-educational. The perfunctory school field trip to a science center, or other informal science education venue, is now considered a more essential component to K-12 science content enrichment. Most critically, science centers expose both teachers and students to modern science concepts, practicing scientists, and hands-on, minds-on experiential learning.

The National Science Teachers Association (NSTA) defines informal science as generally referring to programs and experiences developed outside the classroom by

institutions and organizations. According to recent NSTA public information materials, a growing body of research indicates the power of informal learning to spark curiosity and engage interest in the sciences during school years and throughout a lifetime. The importance of learners' active engagement in science through experiential, relevant, and contextually rich activities has more than sixty years of data and commentary from science educators supporting its effectiveness (Csikszentmihalyi & Hermanson 1995; Dewey, 1939). At informal science centers the translation of modern science is often presented through experiential K-12 classroom or field programs with explicit grade-specific topics related to science content standards. Programs also provide opportunities for teachers' professional development and parental involvement. However, a significantly higher percentage of schools that visit science centers do not participate in programs, preferring instead, to expose students to science learning through exhibits. Regarding the general public—multigenerational visitors who come to a science center for unstructured learning and entertainment, may attend specialized programs for adults and children; however, the key interface for public learning are exhibits. In conclusion, for school and public science learning, exhibits play the most critical role at informal science centers.

Learning Science from Exhibits

Exhibit development at science centers is responsive to, and inspired by, the major discoveries in science and technology that are changing our world. Consider the invention of electricity as an example of how science discovery can change our lives, and subsequently, how science exhibits make meaning of such scientific invention. Designing exhibits for learning is a challenge, especially in today's world where scientific research,

exploration, and discovery is accelerating at a rapid pace. Advances in technology have allowed scientists to make extraordinary discoveries—from nanotechnology (constructing things one atom or molecule at a time or using programmed molecular sized robots (nanobots) that, as an example, can treat disease from inside the human body—to animation of mathematical models simulating the evolution of our universe. The role of technology in our lives has become so essential and transparent, that its long-range effects can hardly be envisioned. The expansion of technology has been increasingly making its way into science centers for use in exhibits to translate and make meaning of modern science research. The tools of science research and discovery are now becoming media for innovation in informal science education.

An emerging technology being applied to science exhibits is visual technology. Visualization technologies allow learners to become immersed, virtually, in all aspects of science—from sea to space, through the use of powerful images from satellites and space probes, such as Mars expedition robots; submersibles traversing the seafloor; and for medical research, creating three dimensional replications of the human body and its systems. Immersive visualization technologies, along with other technological advances, are changing the way we see and experience our world. The *seeing* of our world is cognitive in translation and can stimulate the expansion of our intellectual understanding, consciousness, and the creative process. Immersive visual simulations of real environments intensify visualization of the unseen aspects of our world, such as the systems and processes of Earth and space. A goal of scientific visualization is to capture the dynamic qualities of these systems or processes in images. Scientific visualization, which uses computer graphics to transform data into images, now enables scientists to

assimilate enormous amount of data from scientific investigations. Visualization was needed to understand DNA sequences, molecular models, brain maps, fluid flows, and cosmic explosions based upon mathematics. Demand for *interactivity* of images by scientists was a catalyst to advanced computer research and development, resulting in the emergence of computer-generated graphic images that can simulate real environments called virtual reality (National Center for Supercomputing Applications, 1995).

Virtual Reality (VR) has been an effective tool for decades training commercial and military pilots, and for use by astronauts to simulate conditions of outer space and planetary expeditions. Oceanographers can virtually explore the conditions of our oceans in a similar capacity. VR technology has the potential to innovate science education exhibits at informal science centers by creating new contexts for learning and adapting new scientific insights—helping to foster a scientifically literate public.

As an evolving educational technology, however, VR is only at its inception, and its use as an application in science exhibits, extremely rare. Because of the expansion of science learning centers, nationally; the newly acquired prominence of informal science education as a model for innovative formal learning; and the emergence of virtual technologies for use in science research and exploration, there is a critical need to investigate the effects of VR technology on science learning.

Problem Statement

Within the context of the informal science center, exhibits are the key interface between scientific discovery and public education. Virtual Reality (VR) proposes to enhance the effectiveness of science learning through its immersive, interactive technology.

Potential of Virtual Reality

Suggestions of the potential benefits of VR on learning are related to VR's flexible and adaptive interface, which are assumed to have an effect on learning (Ballard, 1992; Bricken, 1991; Cromby, Standen, & Brown 1996; Holden, Bearison, Rode, Rosenberg, & Fishman, 1999). In virtual environments learners have the ability to move freely—observing objects and environments from above or below, and picking up and manipulating virtual objects for examination—a rather critical aspect of informal science learning. In addition to the usual science laboratory investigation experienced in schools and informal science centers, VR can provide learners with more in-depth investigation of rare environments modeled from mathematical data, such as of a planet's surface and observations of physical processes not normally visible. Bricken (1990b) describes VR's potential for learning given that participants can use their senses, such as hearing, seeing, and touching and using natural physical and perceptual interactions, such as moving, talking, gesturing, and manipulating objects. VR can provide opportunities for immersive learning without restriction of the physical world, thereby controlling time, scale, and physics experimentally (Bricken, 1991; Bricken & Byrne, 1993; Winn, 2002).

Although VR may be a promising technology for improving education, Newby (1993 as cited in Jonassen, 1996), commented that few articles have been found in the literature describing VR research, or applications in progress. Subsequent to the author's findings research studies have been conducted; however, research has been limited in number and scope. Strangman and Hall (2002) conducted an extensive survey of the literature on the demonstrated effects of VR and computer simulation on learning from 1980 to 2002. The authors found an abundance of literature on VR in K-12 education, but

only one (Ainge, 1996) was a refereed journal article. Youngblut (1998) provides an overview of research efforts in education using VR technology. The author suggests that the review of VR's application was limited in scope and depth, serving more as a guide to further VR research efforts.

With few research studies on learning in VR environments, informal science centers whose core mission is providing high-quality informal learning experiences, must address the important issues regarding the pedagogical value of VR technology for use in science learning at exhibits (Cazden et al., 1996).

Prior Exhibit Research

In 2002, the Reuben H. Fleet Science Center in San Diego, California launched a Virtual Reality (VR) exhibit, *Smoke & Mirrors*. An evaluation by Thomas Kiefer Consulting in 2003 indicated that the exhibit was ineffective in communicating its content messages and visitors reacted negatively to the multimedia, interactive virtual experience. Lynne Kennedy, Director of Exhibits and Education at the Fleet Science Center, described the results of the Thomas Kiefer exhibit evaluation:

Based upon our experience with two large-scale interactive Virtual Reality exhibits, we knew that virtual reality was a very popular and engaging medium for all ages. We firmly believe that this medium has a great deal of potential as a tool for teaching informal science. Although there was much optimism in the potential success of *Smoke & Mirrors*, visitor responses to the exhibit have been resoundingly poor. We anticipated that the virtual reality experience would have helped visitors understand the core content but apparently the exhibit is not as user friendly or instructive in science content as we had hoped. (p. 3)

As a result of the evaluation, the Fleet Science Center intends to replace the exhibit's anti-smoking content with a new science topic presented in VR. Critical research data is needed on the interplay between the characteristics of the exhibit's design and the negative and positive effects of VR on visitor learning, assessing the distinct

effects of visual imagery, moving images, sound, narration, and interactive tools.

Research results will inform the redesign of a new VR exhibit at the Fleet Science Center and contribute to the future design of VR exhibits at informal science centers.

Research Questions

The study investigated the following two research questions on VR learning at the *Smoke & Mirrors* exhibit—each question examining four subareas associated with the exhibit’s technology interface:

1. What aspects of the *Smoke & Mirrors* virtual reality exhibit are shown to facilitate learning?
2. What aspects of the *Smoke & Mirrors* virtual reality exhibit interfere with or detract from, learning?

The following sub-areas to research questions one and two were investigated: (a) effects of navigational strategy, (b) effects of visual elements, (c) effects of sound and narration, and (d) effects of interactivity.

Significance of Study

The purpose of any applied field, such as educational technology, is to improve practice. With few research studies on learning in VR environments, informal science centers, whose core mission is providing high-quality informal learning experiences, must address VR’s pedagogical value as an exhibit. Research on VR learning has thus far focused on rehabilitation medicine; military and professional training programs; distance learning; educational software; and VR in schools. Further research contributes necessary data to understand the best uses of VR as a learning tool at informal science centers. The study specifically differentiates the characteristics and influences within the virtual

environment, such as the effects of visual imagery, text, navigation, interactivity, sound, narration, and interactive tools and their enhancing or detracting effects on participant learning. Results will directly inform the design and development of a new VR exhibit at the Reuben H. Fleet Science Center, and contribute needed research on VR for the development of future exhibits at informal science centers.

Rationale and Theoretical Framework

The theoretical framework for the design and development of interactive, multimedia exhibits has been grounded in cognitive theory (Glaser, 1976; Reiser, 1987; Winn, 1989), based primarily on behavioral psychology. Because of research on learning (Bransford, Brown, & Cocking, 2000; Collins, Brown, & Neuman, 1989; Resnick, 1987), instructional design has been moving away from its roots in cognitive theory, a theory that assumes behavior is predictable. For instructional design, that would mean behavior could be prescribed. The field of educational technology, however, is moving increasingly towards constructivist theory, which is learner-centered (Brainerd, 1978; Bruner, 1960; Csikszentmihalyi & Hermanson, 1995; Mattoon & Mowafy, 1993; Vygotsky, 1978). Theoretically, the challenge in instructional design revolves around the fundamental differences that define a learning environment versus an instructional program. Immersive environments, such as VR, can provide learners with freedom to select and chose how they want to learn in that environment rather than making choices based upon those prescribed by an instructional designer (Jonassen & Reeves, 1996; Pantelidis, 1995; Reiser, 1987).

Although behavioral approaches require learning events to reach prescribed goals (extrinsic) and constructivist approaches allow for learner control of instructional

objectives (intrinsic), there may be a necessary coordination within the instructional design to provide more scaffold in an experiential VR environment so constructed learning can be reinforced for retention, as well as for knowledge transfer.

Educational technologists have described cognitive equivalents for all stages in instructional design. To achieve more autonomy in the learning experience, designers can create stimulating learning environments whose function is to adapt, in real time, to a learner's needs and interests. VR environments offer the best possibility for realizing this type of flexible and adaptive learning environment (Bricken, 1990b; Bricken, 1991; Collins, Brown, & Newman; Jacobson, 1993).

Science uses rigorous empirical verification to substantiate findings. When scientific findings are found inaccurate, assumptions are modified accordingly. Instructional design of VR for science education should be as rigorously verified to adjust to empirical findings, following the tradition of scientific research (Kuhn, 1970). It is reasonable to propose, accordingly, that the theory and procedures of science research be implemented in the evaluation of educational instruction in exhibits and procedures of instructional design be revised according to research findings.

Assumptions and Limitations

The Fleet Science Center's *Smoke & Mirrors* exhibit content will be replaced; therefore, research focused on participant reactions to the exhibit's instructional design and other characteristics of the virtual environment assessing how essential VR characteristics affected learning. The prior evaluation by Thomas Kiefer Consulting in 2003 provided data on participant content learning; therefore, it was assumed that results

of the current study would not be skewed in any manner by focusing on areas of content learning not under investigation in the prior study.

The *Smoke & Mirrors* exhibit was initially designed for ages 12 and above. Research focused on participants 18 and above. Although the study had agreement across all ages, future studies with a broader range of participants could provide data to expand upon results and contribute to more generalized instructional design approaches.

Chapter Summary

Science centers are critical venues for improving science education in the United States. Within the context of the informal science center, science exhibits are the key interface with the public. Virtual Reality (VR) has emerged as a leading technology for use in science exhibits with its highly immersive, interactive, and multimedia capabilities. With few research studies on learning in VR exhibit environments, informal science centers must address issues regarding VR's pedagogical value (Cazden et al., 1996).

The study investigated a unique and rare VR exhibit at the Reuben H. Fleet Science Center in San Diego, California, focusing on the interplay between the characteristics of the exhibit's design and the negative and positive effects of the exhibit's visual imagery, moving images, sound, narration, and interactive tools on learning. Results are intended to inform the immediate redesign of a new exhibit at the Fleet Science Center and contribute to the future design and implementation of VR exhibits at other informal science centers. Chapter Two, which follows, provides a review of the literature on VR and aspects of exhibit design and informal learning with discussion. Chapter Three discusses the study's research method and design.

Chapter Two: Review of the Literature

This chapter, which presents a review of the literature on Virtual Reality (VR) covers the history of VR development and its evolution as a media for use in entertainment, education, and science. Although in use over the last two decades for modeling in these areas, VR technology is only beginning to emerge as a promising visual technology for exhibits at informal science centers. Direct application of VR for use in exhibits has been limited, if not rare. Use of VR in other contexts has resulted in findings that do not show very much benefit to learners. Although each context for teaching and learning can apply VR technology differently, the following review intends to address findings and applications of VR that indicate potential for future application in science education exhibits, along with promising research on VR being conducted in cognitive and physical rehabilitation education that also may be transferable in the future to exhibit learning. A brief discussion of informal science education is presented to connect informal science education instructional methods with approaches to VR exhibit design strategies. Review of literature included (a) extensive bibliographic reviews on VR in education; (b) surveys of the literature on VR; (c) Association of Science and Technology Centers' resources; (d) ERIC digest database; (e) proceedings of studies presented at conferences; (f) VR research and development at universities; and (g) professional reports of VR software and hardware product development.

History of Virtual Reality

Since the mid-1940s, both the definition of virtual reality and its accompanying applications have evolved for use in the military, entertainment industry, science, and education. The following sections provide an overview of VR's emergence.

Definition and Development

Virtual Reality (VR) is generally defined as a computer interface that provides learners with perceptual and psychological immersion in a virtual experience. VR is thought to have emerged in the 1980s after the development of 2D computer software by Warren Robinett that became an early model for immersive learning environments. In 1989, Jaron Lanier, one of the first developers of immersive devices, such as the DataGlove™, has been credited with coining the name virtual reality for immersive devices. *Virtual*, is a term used to define real objects recreated in a computer-generated environment. Virtual Reality, virtual worlds, virtual environments, and cyberspace are terms often used synonymously (McLellan, as cited in Jonassen, 1996).

Bricken (1991) discusses the potential of virtual environments, as environments where learners have exploratory freedom to observe objects and events. Such events may allow viewing of objects from above and below and use of interactive tools to retrieve and examine virtual objects within an environment. The Johnson Space Center at the National Aeronautics and Space Administration (NASA) uses VR simulations for the training of astronauts, including the viewing of planets modeled from robot probes, satellites, and mathematical data.

In Winn, Windschitl, Fruland, and Lee (2002) VR is discussed as providing an “illusion” of being in another place. The feeling of being present, which is perceptual, is often described as *cognitive presence* (Bricken, 1990a), a distinguishing characteristic of VR. The concept of immersion can refer to being surrounded in 3D, but not exclusively (Lavroff, 1992), since many other types of VR experiences create a sense of immersion. The term *presence* is often used synonymously with the term *immersion*. Since presence

is a defining characteristic of VR, its effect on learners can enhance or detract from the virtual experience, as well as exploration within the virtual environment (Zeltzer, 1992 cited in Winn et al., 2002).

In summary, VR is a computer-generated environment where the learner experiences being immersed in the environment, perceptually, psychologically, and sometimes physically.

Applications

Three major areas of VR have been applied by the military, entertainment industry, and science research.

Military research. The military and industry funded development of technology that would simulate effects of flying for pilot training in the 1940s. Cockpits were built to create the effects of flight by using motion platforms, but these early simulations were limited in providing needed visual feedback to pilots. Modifications to simulations included adding videos to the cockpits. With innovation in computer graphics in the 1970s, flight simulators emerged, and by 1979, head-mounted displays (HMDs) were added to improve upon simulated virtual experiences. New software, hardware, and motion-control platforms emerged in the 1980s that allowed pilots to navigate through highly defined virtual worlds, including those that produced battle scenarios. This extensive innovation in technology subsequently created video games (National Center for Supercomputing Applications, 1995).

Entertainment. The use of computer graphics was not restricted to the military. The term, special effects, evolved from the movie industry's use of computer- graphics in

movies, such as *Star Wars*, *Terminator*, *Jurassic Park*, and *Matrix* that used specialized effects to create imagined environments and characters.

Other innovations in entertainment occurred in the area of gaming. Industry developed the DataGlove™, which was an interactive tool, but instead of using a joystick or trackball, this device had the ability to detect hand motion. It was used to link a person's hand gestures, like the gestures of a composer, to a music synthesizer, which would translate gestures into music. The *Nintendo* game incorporated a PowerGlove as a tool to play the game, which was adapted from the original DataGlove™ (National Center for Supercomputing Applications, 1995).

Science research. Through VR, scientists can process mathematical data using computer graphics to transform data into 3D images. Some of the recent breakthroughs in scientific understanding used visualization technologies to gain insight into specific systems and process, as an example, DNA sequences, brain mapping, fluid dynamics, and cosmic explosions. Although in the 1980s scientists used the movie industry's special effects animation for visualization, animation capabilities for scientific rendering were limited. Special effects animation did not provide interactivity. Interactivity was required to see immediate changes in systems and processes reflected in the imagery. In the 1980s, demand by scientists for interactive environments to comprehend data, initiated high-performance computer research and development. Computer research resulted in a new generation of computers with high-powered capacity to render graphics interactively, which furthered the emergence of virtual reality environments by the late 1980s (National Center for Supercomputing Applications, 1995).

Types of Virtual Reality Interfaces

Since the 1980s, application of VR technology has varied, and its many forms have been characterized and classified, as follows:

Jacobson (as cited in Jonassen, 1996) characterizes four types of common virtual realities: “*immersive, desktop, projection, and simulation.*” Thurman and Mattoon (as cited in Jonassen, 1996), classify “dimensions” of a virtual experience, differentiating and measuring virtual reality against the real environment (and objects). The authors propose categories to measure the degree to which the learner is involved in the virtual experience, and the degree to which the virtual experience replicates real environments and objects. Brill (1994), defines a classification system for VR consisting of immersive and non-immersive virtual environments that appears to be widely used in differentiating types of VR experiences:

1. *Immersive First-Person* uses a head-mounted display or sensory glove to immerse the learner inside the virtual environment.
2. *Through the Window*, also known as *Desktop VR* (Lavroff, 1992) often uses a standard computer monitor with an interactive device to navigate through a 3D virtual environment.
3. *Mirror World*, is a second-person experience where the learner is outside of the virtual environment but can interact with their own image projected inside the environment, and the learner can interact with virtual characters and objects.
4. *Waldo World* is a system where the learner uses a sensory device, such as motion detector, to control an animated character or robot on the screen in real-time.

(Waldo World is associated with Robert Heinlein’s (1965) science fiction story.)

5. *Cab Simulator Environment*, is a first-person experience that uses simulators to provide single or group immersion in a virtual experience, such as a flight simulator for pilot training, or simulators commonly used at informal science centers and places of entertainment.
6. *Chamber World*, a VR projection theater controlled by several computers, such as the SONY Omnimax 3D theater, that provides immersion with sensory and auditory experiences.
7. *Cyberspace*, a virtual group experience achieved through linking networks of computers (similar to telephone networks). Networked virtual experiences include Multi-User Simulated Environments (MUSEs) and Multi-User Domains (MUDs). Some of the applications of cyberspace technology are being explored for education, military, and entertainment applications. William Gibson coined the term “cyberspace” in his novel *Neuromancer* (1984).
8. *Teleoperation*, allows for the control of a robot or other device from a distant location. A well-known example in science education is Robert Ballard’s (1992), Jason Project (1995; McLellan, 1995), which exposes students to research scientists worldwide who are examining Earth’s biology and geology. Students in the Jason Project can operate an unmanned submarine. In the same manner, students can control NASA’s Telepresence-controlled Remotely Operated Underwater Vehicle (TROV) (NASA, 1994).

Research on Learning in Virtual Reality Environments

Strangman and Hall (2002) conducted an extensive survey of the literature from 1980 to 2002 reviewing the literature for evidence on the effectiveness of VR and

computer simulation in K-12 education settings. Of the 31 studies cited, only three research investigations were found on VR, which are mentioned below. Strangman and Hall's review of VR found student enjoyment of VR was high, but with respect to science learning, results did not show clear evidence that VR could produce longstanding results. Also mentioned by the authors, was that the contexts for which VR might show effectiveness, those contexts were still in need of definition.

Strangman and Hall's summary of VR literature begins with Ainge's (1996) study conducted with students in grades five, six, and seven who participated in a desktop VR program by VREAM Virtual Reality Development System. The study required students over four sessions to use the program to construct virtual environments using three-dimensional shapes. Students who used the VR program were able to recognize those shapes after using the program. Students who did not use the program and built environments with paper did not show similar shape recognition. Results also showed more enthusiasm in students using the VR program. Strangman and Hall caution that enjoyment in using VR has been well documented but evidence for VR's sustained enthusiasm remains a question for future research. Song, Han, and Yul Lee's (2000) study indicated that students learning geometry using VR solved geometry problems more effectively than students who were learning geometry verbally; however, the higher performing students (who used VR) were not more effective at solving geometry problems when they did not use VR. This indicates that learning was not longstanding. Taylor's (1997) study focused on 2,872 middle and high school students' responses and perceptions of being in a virtual environment and identified influences on students' enjoyment of VR. Students attended a 30-minute presentation on VR, and then visited an

immersive VR environment. Questionnaires were used to rate experiences. Results indicated high levels of enjoyment navigating the VR environment; for many, difficulty with the navigating; and for some, navigating was somewhat disorienting. The author suggests a need for technical improvement of the VR environment to improve students' ability to observe the environment and reduce disorientation.

Yeo, Loss, Zadnik, Harrison, and Treagust (1998) conducted a videotaped qualitative study of 10 undergraduate students in physics using a commercial interactive software program teaching physics concepts. Findings indicated students needed intervention for conceptual understanding. To improve instructional design of interactive media, the authors recommend that psychologists, science educators, and content specialists contribute to, and evaluate, multimedia programs. Tobin and Dawson (1992, as cited in Yeo et al., 1998) also mention that the design of science-learning media has not integrated teachers' expertise and knowledge, as a point of its pedagogical weakness.

Youngblut (1998) reviewed the effects of students, in grade levels from elementary to undergraduate, using 43 different pre-developed VR applications, and 21 virtual world projects where students build their own VR environments. Approximately 75% of the students used head-mounted devices or displays to create immersive learning experiences. The author cautions that results of the study's evaluation of school-based applications are limited in scope, as students used the program, in some cases only once, leaving questions regarding the long-term effectiveness of VR on student learning. The author concluded that the findings on VR applications under investigation did not significantly support education, nor did the findings reveal which of the characteristics of

the technology supported learning. The study recommends future research on the development and evaluation of VR.

Virtual Reality in Rehabilitation Education

Researchers are beginning to collect valuable information about the usefulness of VR for application in rehabilitation (Riva, Wiederhold, & Molinari, 1998). Current research is investigating the use of VR in brain damage assessment, rehabilitation, and in occupational training of people with learning disabilities, such as cognitive assessment and retraining of attention, memory, and spatial skills; assessment and training of motor skills; occupational training; and training powered wheelchair use. VR is also used to assess the driving ability of patients following vascular or traumatic brain injury; train manual wheelchair use; assess the prospective memory ability (capacity to remember to perform future actions) of vascular brain injury patients; assess spatial memory using functional magnetic resonance imaging; and development of an interactive multimedia package for training people with learning disabilities for employment in an office environment.

Riva et al. (1998) provide a meta-analysis of studies in rehabilitation education. One such study cited by the authors is research investigating successful rehabilitation with children by McComas, Pivak, and Laflamme (1998) who provide examples from published research focus using VR to help children with disabilities, and VR's effectiveness. Projects mentioned by McComas, Pivak, and Laflamme show positive effects on VR. The following lists effects of VR on children with disabilities, with research studies cited for further reading. Children were shown to gain a new perspective with increased social participation and access (Inman, Loge, & Leavens, 1997; Max &

Gonzalez, 1997); gaining of self confidence, development of competence, self control, and mastery (Bricken, 1990a; Inman, Loge, & Leavens, 1997); increased expression of independence (Standen & Cromby, 1995); practicing of communication skills (Casey, 1995; Muscott & Gifford, 1994); and having fun and being distracted from disability (Hirose, Taniguchi, Nakagaki, & Nihei, 1994; Pantelidis, 1993). Although many positive results have been shown the authors recommend future research to investigate the transfer of skills when children move from the virtual environment to the real environments, as VR has not shown complete and successful transfer of newly learned skills, especially in the area of physical restrictions.

Virtual Reality in Exhibit Design

Providing successful learning exhibits in VR is nothing short of composing a symphony. The balance between all elements of exhibit design is essential for an effective learning environment. As in real life, regardless of the learner's motivation, if the atmosphere is not conducive for learning, learning will be compromised. Often, learners are distracted at exhibits by ambient noises, as well as operational aspects of an exhibit, such as visual imagery, interactive tools, sound effects, and exhibit spaces that do not embrace group learning. Aspects of exhibit design potentially useful for future VR environments are discussed in the following literature.

Immersion in Exhibits

Because perceptual and psychological immersion in the virtual experience is an essential characteristic of VR, researchers have been interested in learning how computer-generated environments create immersive effects. *Flow*, which is a cognitive state characterized by total engagement in an experience with degrees of exclusion of

external awareness and feelings of timelessness (Czikszentmihalyi, 1990; 1998) is also descriptive of feelings of immersion in virtual environments.

Computer games are known to provide sustained engagement over long periods of time. Malone and Lepper's (1987) work, which has guided research on gaming, shows that *challenge, curiosity, control, and fantasy* foster intrinsic motivation, and play an essential role in increasing and sustaining interest and engagement in the game experience. Additional findings by Hedden (1998, cited in Winn et al., 2002) show that success in sustaining game-playing is based upon game designers applying strategies known to effect motivation, such as those characteristics found in Malone and Lepper's (1987) study. Games provide a powerful sense or illusion of control, and control has often been mentioned as a key reason why people become captivated by game experiences. Increased control is motivating, and decreased control reduces motivation (Dweck, 1975).

Use of Interactive Text

In designing interactive exhibits, Norman (1988) mentions that instructional designers often use text (words) on the computer screen to describe a desired action (e.g., click here) or use labels in front of objects to communicate what the desired action is, and where it is to be done. This requires highlighting, outlining, or depiction of an actionable object—an object that is interactive. Gibson (1979) suggests that words are understood more quickly than graphics, even when using a well-known and understood graphic and words plus graphics are the most readily understood (Norman 1988). McManus (1989) has shown the importance of interactive text in increasing an exhibit's holding power. Attracting power grabs the attention of learners, while holding power sustains learners'

attention while at the exhibit. Exhibits that have low attendance, or are skipped entirely, may lack attracting power. Both holding power and attracting power are factors that can indicate the success or failure of an exhibit.

Use of Interactive Tools

If the technology interface, such as the interactive tool, does not have ease of use participants will not expend their cognitive energy on learning content; they will expend their energy on trying to figure out how to make the tools work (Gibson, 1979). The effect of cognitive load on learning is further supported by Park and Hannafin (as cited in Hasselbring, Goin, Zhou, Alcantara, & Musil, 1992). Park and Hannafin found that high levels of interactivity caused high cognitive load and interfered with learning.

Csikszentmihalyi (1990; 1998) argues that an optimally challenging activity relies on balancing the demand of the activity with the learner's capability for performing that activity. Conversely, discouragement, frustration, irritation, and anger can occur when uncontrollable and repetitive annoying events occur in technology applications and when activities are required of a learner that cannot be accomplished.

Design affordances. The term affordance was coined by James Gibson and describes the *potential for action* in an interactive technology exhibit (Gibson, 1977). Gibson mentions, as an example, that our perception informs us what we can and cannot do with objects in real and VR environments. Ryder and Wilson (1995) suggest that interactive tools become *affordances* (the potential for action) if they extend our capability for manipulating objects within the virtual environment. Conversely, if the tools are not communicating potential for action, learners will spend their time at an

exhibit trying to learn how to use the tools effectively. According to Gibson (1977), this leads to cognitive drain, fatigue, and the ultimate rejection of the exhibit.

Designing for Group Learning

Informal science learning centers have not been particularly effective in addressing learning in groups, and often repeat the same problems in their exhibit design. Borun et al. (1998) found that families, who are a primary audience for science museums, are not offered many group-oriented exhibits to interact with. Most exhibits are designed for individual users, not for paired or group-learners. This is a serious problem according to Hilke and Balling (1985), since groups (more than one person) come to the museum with an agenda that is part social. This may offer additional insight into the limited science learning often associated with exhibits, as collaborative learning, as a form of intervention can help students, adults, and families make-meaning of the informal science experience.

Instructional Design

Of the plethora of literature on museum education, most of the literature discusses object-based learning, which commonly refers to learning from museum artifacts. Artifacts are used in informal education to stimulate and encourage investigation of the object and by doing so to gain an understanding of the object's historical and scientific value. In science centers, specifically, object-based learning is not the core focus. Educationally, the focus is *experience-oriented*, where learning takes place through active exploration and investigation. Experiential learning is learner-centered—directly engaging the learner in the acquisition of critical cognitive processing skills beyond those acquired through the attaining of objective knowledge. The current movement in informal

education is to provide more experiential activities, as there is agreement among educators and psychologists (Resnick, 1987) that comprehension and reasoning evolve cognitively through engagement and processing of experiences, not through passive learning of facts.

As there are a variety of ideas and definitions about what constitutes learning, the most prevalent definition of informal learning includes *hands-on*, *minds-on* activities and experiences. The term hands-on learning is said to have emerged in the 1960s although activity-based approaches to learning were part of science education since the 1860s (Dewey, 1939; Kappa Pi Lecture Series, 1997). The concept of hands-on science is predicated on the process of scientific inquiry. Science activities must actively engage learners through experimentation and the manipulation of objects and materials, and build on childrens' innate inquisitiveness (Shapley & Luttrell, 1993). In recent years hands-on science has been enriched to *minds on science*, referring to exemplary teaching (Hassard, 1992). The term minds-on is used synonymously with *heads-on science*. Flick (1993) describes the emergence of minds-on learning as being introduced by teachers to expand the concept of hands-on to the very substance of what students are learning while engaged in hands-on activities.

Summary of Literature Review

Essential to the success of a science center is how well exhibits model effective strategies for learning; therefore, it is critical that issues regarding VR's pedagogical value for science learning be investigated (Cazden et al., 1996). Evidence for the effectiveness of VR on learning is scarce (Strangman & Hall, 2002). In fact, Strangman and Hall found only three research investigations from 1980-2002 of VR in K-12

classrooms, and concluded in their summary of the literature that despite reports of students' positive experiences, evidence was not provided that VR could provide longstanding results on science learning. The authors also indicated that the contexts used for VR learning where positive results were found were not clearly defined.

Newby (1993, as cited in Jonassen, 1996), mentions that VR technology has the greatest potential for improving education; however, in the area of K-12 education, the author found almost no articles in the literature describing VR research or its potential. Subsequent to the author's comments new research has been conducted; however, research has been limited in number and scope. Unlike instructional programs, VR allows for controlling the physics of environments by allowing opportunities for learning without learners being limited by the physical world (Bricken, 1990a; Bricken & Byrne, 1993; Winn, 2002; Winn et al., 2002).

Studies are being conducted energetically in the area of rehabilitation of disabled children and adults (Riva et al., 1998). The authors discuss findings on rehabilitation education using VR that indicate effective learning. VR research in this area may be generalized to other populations of learners in other venues, such as informal science centers and exhibits.

One reason for limited findings supporting VR is the scarcity of research studies. Trends seem to be emerging in some studies demonstrating positive effects but there is not enough research to replicate findings, or expand upon them. As an example, Winn (2002) discussed a VR environment where students used head-mounted equipment and did show some improved science learning. Findings in military training, when coupled with simulations, were found to be effective in skills training. Visual media using

simulations were found to help student comprehension of science ideas (Hasselbring et al., 1992). Research in rehabilitation medicine has demonstrated notable progress in improving cognitive, physical, and social skills. Although results are specific to the venue, and research is scarce, future research can build on these findings, which may, as an aggregate, demonstrate VR's positive effect on learning.

In the area of exhibit development, VR exhibit technology can cost hundreds of thousands of dollars for one installation, and use of valuable facility space. These are serious prohibitory factors; however, the cost of producing VR is beginning to decrease, and the technology is becoming more mobile, which may inspire science centers to consider developing VR exhibits, especially with respect to the capability of this medium to demonstrate 3D science learning environments for experiential learning. With the expansion of visitor attendance at science centers yearly; the extraordinary breakthroughs in science research and discovery essential for teaching and learning; and the dire need in America for improved science learning, there is now as critical a need for new science learning tools, as there was in the 1980s for visual interactivity in science. As indicated, there is an urgent need for new research that can inform informal science centers how to evolve VR as an effective tool for science learning. Such research will further science education innovation, and that is critical for our nation's future.

Chapter Three: Methodology

The intent of the research was to differentiate specific causal characteristics and influences of Virtual Reality (VR) that attracted and detracted from learning at a science exhibit. The *Smoke & Mirrors* exhibit at the Reuben H. Fleet Science Center (Fleet Science Center) in San Diego was the site of a case study. The study investigated the interplay between the elements of the exhibit's design focusing on assessment of the separate and interactive effects of the exhibit's instructional design, including interactivity, pictorial imagery, navigation, sound, auditory narration, and interactive tools. Case study methodology, utilizing visitor observations and interviews was employed to collect in-depth data on visitor reactions. Results of the study will inform the forthcoming design of a new VR exhibit at the Fleet Science Center. A prior, brief mixed-methods evaluation of *Smoke & Mirrors* was conducted in 2003 by Thomas Kiefer Consulting and contributed background to the investigation and its future implications and strategies.

Case Method

Case design strategy (Stake, 1995) was selected as the method for research to focus inquiry around *Smoke & Mirrors*, an interactive VR exhibit at the Fleet Science Center in San Diego, California. Written and audiorecorded observations and interviews with participants, during and after their exhibit experience, identified and differentiated the causal characteristics and influences of the exhibit's VR experience that effected learning. Case study methods prescribed by Miles and Huberman (1994) allowed research to develop rich explanations and descriptions of participant reactions that might not be otherwise identified, or treated as operationalized variables in a statistical study.

While the research design was emergent, the following delineates the structure of the research process.

Sample and Population

The Fleet Science Center attracts approximately 500,000 visitors annually. Based upon random sampling surveys in April 2000, 87% of visitors are from California and 71% from San Diego County. An earlier survey showed that the age levels for visitors are: 31% younger than 18; 26% between 18 and 34; 29% between 35 and 50; 7% between 51 and 64; and 7% are 65 and older.

A total of 14 visitors were sampled, ages 18 and above. Six participants were female and eight male. The age range for the study represents 69% of Fleet Science Center visitors.

Participant Selection

Participant-selection was based upon the study's required age range and participant availability to participate in a 7-minute observational process at the exhibit and a 45-minute post-exhibit interview at the Fleet Science Center in San Diego. The Fleet Science Center visitor pool was the sole source of research participants.

A poster sign requested visitors to volunteer for research on the *Smoke & Mirrors* exhibit. The recruitment poster was initially placed on an easel at the entrance to the Fleet Science Center where visitors congregated to purchase admission tickets. Recruitment of participants began prior to the exhibit's opening, and continued until the last showing. The *Smoke & Mirrors* exhibit was a timed exhibit that began at 11:15 AM, running

throughout the day at a quarter to, and a quarter after the hour, with the last showing at 4:45 PM. Many visitors declined from participating in the research because the timing of the exhibit interfered with the science center's popular IMAX films showing continuously throughout the day. The easel with recruitment sign was repositioned throughout the day to capture the attention of visitors exiting the IMAX theater. Other areas for recruitment were within the general exhibit hall, or at the *Smoke & Mirrors* exhibit. The most successful recruitment areas were at the IMAX theater exit and in front of the *Smoke & Mirrors* exhibit.

Visitors either approached the recruitment area asking questions about the research, or were directly approached to participate. Visitors who were approached were those that were perceived to be age 18 or above; were observed interacting with exhibits; or casually walking through the exhibit space. Visitors who were not approached were single adults with children under age 12. Children under age 12 were prohibited from participating in the *Smoke & Mirrors* exhibit; therefore, a single adult would be unlikely to leave a child alone in the exhibit hall, and they would not be advised to do so. Many participants came to the science center in groups. At times, a group of visitors participated in the exhibit experience at the same time as the selected participant; however, group members were not interviewed after their experience, as observation and recording of the research participant during the exhibit experience was an essential part of the research.

Inquiring visitors were informed about the process and procedures of the research and research goals. Of those visitors who expressed interest in volunteering, selection was based upon the two criteria: age range and time availability.

After a participant was selected, participant was asked to read the *Informed Consent Statement*. Aspects of the study were reiterated in follow-up discussion, including the time commitment, audiorecording of the interview and observation process, and the right to discontinue participation at any time during the process. As the study was anonymous, consent signatures were not obtained to avoid collection of names and identities of participants.

All research activities were made public to participants (Merriam, 1988). Family and friends with the participant were informed of the process, timeframe of the research, and location of the exhibit and classroom where the interview would be conducted. A convenient seating area was available outside the interview classroom for participant friends or family. Upon agreement to participate, participants were asked for initial data related to their prior experience with Virtual Reality, which was noted on the interview instrument prior to entering the exhibit.

The Fleet Science Center reviewed and approved research protocol; therefore there were no anticipated problems with participant recruitment or data collection process. Visitors who volunteered to participate faced no physical or psychological hardships. Research questions did not delve into any personal or psychological dynamics of the participant. Because visitors gave up time at the facility to participate, delay in the research process could have caused some degree of discomfort. To limit such associated risks, strict adherence to the agreed-upon timeframe of the research was maintained.

Compensation and Incentives

There were no financial costs that accrued to participants in the study. Because participants gave up a significant amount of time at the facility to participate in the

research, compensation was offered with two free admission tickets to the science center, including admission to two IMAX films—a total value of \$23.00. Ticket value was based upon the general price of admission to the science center and IMAX film. Participants who had to drop out of the research received one admission for the day of the research. If, during the course of the research a problem occurred with the exhibit, or at the facility, such as a fire drill, participants were entitled to full compensation of two admission tickets with two IMAX films.

Research Process

The research process consisted of a pilot study to test instrumentation and research questions, prior to the implementation of the formal research.

Pilot Study

A pilot study was conducted at the Fleet Science Center in February 2004 to test the observation and interview instruments with Fleet Science Center staff. Results of the study informed the development of the final instruments, formal research process, and refined final procedures. A final site-visit was conducted in April 2004 to confirm interview and observation protocols; review instruments and research questions; visit the interview sites; confirm optimal areas for participant recruitment; and confirm scheduling of research at the exhibit site with exhibit operation staff.

Formal Research

Formal research consisted of participant observations at the exhibit and post-exhibit experience interviews.

The exhibit was a 7-minute timed experience. Participants began the exhibit experience on time, and vacated the exhibit at the conclusion, as required of all visitors.

Participant comments were audiorecorded while the exhibit was in progress. Written notes of participant comments and behavior were indicated on the observation instrument.

At the conclusion of the 7-minute exhibit experience an indepth, audiorecorded 45-minute interview was conducted in a classroom across the hall from the exhibit, or in the Education office. To obtain reactions and perceptions of the exhibit, participant responded to a series of guided questions on the interview instrument designed to collect data on aspects of the exhibit's characteristics. Emergent questions were asked, along with follow-up questions based upon comments made at the exhibit during the observation phase. At the end of the research process, participant was escorted from the classroom to the general exhibit area to meet family or friends.

Data Collection

Two instruments were developed to collect written observational and interview data. Audiorecordings collected participant comments and interviews. Additional data from exhibit development documents; discussions with staff; and Fleet Science Center reports were later triangulated with written and audiorecorded data to inform the final conclusions and implications of the study

The observations instrument was based on a prototype previously tested at the Fleet Science Center. Participants were asked, prior to entering the exhibit, to comment on their experience as they were interacting with exhibit. During observations, a formal protocol was not used, however, attention was focused on collecting notations of participant facial expressions; physical gestures, such as pointing to focus areas on the exhibit screen, and any other noticeable and significant behaviors; and notation of

verbalized comments about the exhibit experience. Decisions, such as where to stand to observe participant's interactions were made without compromising participant's experiences and based upon what was salient to the study.

The interview questionnaire was used to query participants on the usability of the exhibit. Participants responded to questions on exhibit interactivity, content, instruction, tools, sound and music, immersion in the virtual experience, navigation, and learning. Interviews were conducted in-person, but semi-structured (Merriam, 1988), guided by pre-written questions. Interviews were flexible in format, allowing for trends and areas of importance to emerge as the participant articulated their exhibit perceptions and experiences.

Participant data was audiorecorded throughout both the exhibit observation and interview processes.

Information pertaining to *Smoke & Mirrors* exhibit development, prior evaluation efforts, print documents, reports, and discussions with staff contributed data to the overall research.

Data Analysis

Each participant was identified with an assigned number. Observation and interview instruments and audiorecordings were numbered and dated to each participant. Written and audiorecorded interview and observation data was transcribed, reviewed, and analyzed for categorization and tracking of key themes, characteristics, and emerging areas of importance. Observed behaviors and recorded comments at the exhibit were compared with follow-up participant responses during the interview to support conclusions. Thematic categorization was further analyzed and synthesized into summary

of characteristics related to research questions and common themes and trends related to subareas under investigation. Further insight into participant perceptions; exhibit design; and identification of main issues related to the research questions were obtained through triangulation with prior evaluation efforts, documents, reports, and exhibit-related discussions with Fleet Science Center. Crosschecking, external peer validation, and reiteration of information allowed for verification of emergent trends (Creswell, 1998).

Clarification of assumptions and biases prior to the study were acknowledged and are reflected in the final report. Truth-value was strengthened by the use of external peer observation of participant recruitment methods; external peer observation of the participant observation and interview process; and peer examination and disclosure of researcher bias. Peer review included validation of audiorecorded data against research findings and dissertation committee review and discussion regarding emergent findings.

To ensure consistency, triangulation of multiple data sources was used throughout the research process. This involved reviewing prior evaluations, documents, discussions, audio recordings, interviews, and observations. The final report includes detailed descriptions of the context and research activities of the study (Creswell, 1998; Merriam, 1988).

Chapter Four: Findings

The study investigated the effects of Virtual Reality (VR) on learning at the *Smoke & Mirrors* science exhibit at the Reuben H. Fleet Science Center (Fleet Science Center) in San Diego, California. Research focused on the interplay between the exhibit's pictorial elements, moving images, sound, narration, interactive tools, and other emergent influences of the exhibit's instructional design. Inquiry differentiated the causal characteristics and influences that enhanced and detracted from participant learning. Recorded interviews and observations of 14 participants (six females and eight males) were conducted in April 2004.

In 2003, Thomas Kiefer Consulting conducted an evaluation of *Smoke & Mirrors*, investigating visitors' retention of anti-smoking content messages and level of attitudinal change as a result of the exhibit experience. Given the extensive nature of the prior evaluation and its focus on exhibit content retention, the current study investigated the effects of Virtual Reality on learning by differentiating the causal characteristics and influences of VR that enhanced or detracted from learning in a virtual environment. Results of the study will directly inform the redesign of a new exhibit at the Fleet Science Center and contribute to the future design of VR exhibits at informal science centers.

Chapter Four is organized into the following sections: Section one presents the study's two research questions; section two characteristics of the study's participants; section two presents the researcher's observations of the exhibit in progress with participants at the exhibit; section three presents findings based upon; section four presents pre-interview data; section five presents results of observations post-exhibit

interviews with participants. Findings will be discussed in relationship to the study's two research questions and subareas under investigation.

Research Questions

Two research questions guided the study's inquiry of the *Smoke & Mirrors* exhibit. Each question investigated critical aspects of the exhibit's instructional design and its effects on learning, examining the interplay between the separate and interactive effects of visual imagery, moving images, sound, narration, and interactive tools to differentiate the causal characteristics and influences that enhanced and detracted from learning.

Research Question One

In response to research question one, "What characteristics and influences of the *Smoke & Mirrors* exhibit were shown to facilitate learning," the following subareas were investigated: a) effects of navigational strategy, b) effects of visual elements, c) effects of sound and narration, and d) effects of interactivity.

Collected data included written and audiorecorded observations of participants as they interacted with the exhibit. Post-exhibit experience interviews engaged participants in guided discussion on the characteristics and influences of the exhibit's narration and instruction; interactivity; interactive tools; visual imagery; sound and music; and learning. Additional input from participants suggested other areas for inquiry.

Collected data in summary, included in-depth interviews, audiorecordings, written notes, observations, reports, and documents.

Research Question Two

In response to research question two, “What characteristics and influences of the *Smoke & Mirrors* exhibit were shown to interfere with or detract from, learning,” the following subareas were investigated: a) effects of navigational strategy, b) effects of visual elements, c) effects of sound and narration, and d) effects of interactivity.

As in question one, collected data for question two, included written and audiorecorded observations of participants as they interacted with the exhibit. Post-exhibit experience interviews engaged participants in guided discussion on the characteristics and influences of the exhibit’s narration and instruction; interactivity; interactive tools; visual imagery; sound and music; and learning. Additional input from participants suggested other areas for inquiry. Collected data in summary, included in-depth interviews, audiorecordings, written notes, observations, reports, and documents.

Participant Characteristics

Fourteen Fleet Science Center visitors, who were selected from the general population of visitors, participated in the study: six females and eight males.

Of these, 11 out of 14 cited *entertainment* as their main purpose for visiting the Fleet Science Center, and 3 mentioned *education* as the reason for their visit.

All participants visited the Fleet Science Center in pairs or groups; only one participant from each pair or group participated in the study.

Breakdown of participant age-ranges per gender is found in Table 1.

Table 1

Participants' Age-Range and Gender

Age-Range	Total	F	M
18-24	3	1	2
25-30	4	3	1
31-36	2	1	1
37-41	1		1
42-46	1		1
47-51	1	1	
52-56			
57 and above	2		2
Total	14	6	8

Pre-Interview Findings

Prior to the *Smoke and Mirrors* exhibit experience, pre-interview data was collected on participants' prior experiences of Virtual Reality (VR); their level of understanding of VR; and their expectations of a VR exhibit.

Expectations of a Virtual Reality Exhibit

Interviews, observations, and audiotapes were transcribed and themes identified. Only four of the participants in the study had any prior experience with VR. Expectations of a VR exhibit stated by more than three participants, including those with and without prior experience, are indicated in Table 2.

Less mentioned themes included: VR would be presented in color, not black and white; have motion and other sensory experiences; and perhaps include an interactive touch screen.

Statements, such as "A person participates in something computer-generated—like an event but the event can be changed by your actions" portray the essence of expectations.

Table 2

Participants' Expected Characteristics of a VR Exhibit

Elements	Responses	No. Responses
Virtual environment	Computer-generated; feeling of being elsewhere immersed ^a in an illusory experience; highly realistic pictures with simulated real events.	14
Movement	Movement of visual imagery.	12
Interactive tools	Hand, head, or eye gear that mimics participant movements in the environment; provides immediate feedback with decision-making, challenge, and results.	11
Instructions	Explanation of game.	9
Music	Background music or music related to the experience.	8
Narration	Feedback on progress of experience	8

^aImmersion is defined as the perceptual and psychological sense of being inside the virtual experience.

Prior Experience with Virtual Reality

Interviews, observations, and audiotapes were transcribed and themes identified. Data showed influences effecting results based upon participants' prior experience. Participants who experienced VR computer and video games anticipated that *Smoke & Mirrors* would have result- and reward-oriented experiences, such as playing the game for points or receiving instant feedback on progress. Ten out 14 participants who did not

play computer games, however, had similar expectations of the exhibit. Participants who experienced VR movies, such as *Matrix*, expected a heightened and more amplified virtual experience with complete immersion in a realistic world.

Results of Observations

The following description of the *Smoke & Mirrors* exhibit is based upon the researcher's observation of participants prior to entering the exhibit and observations throughout the exhibit process. It was critical for the collection and analysis of data that the researcher experience the exhibit along with the participant in order for participant perceptions of the media to be immediate, clarified, and recorded.

A brief overview of the exhibit's intended content messages begins the description of the exhibit process.

Smoke & Mirrors was intended to reveal how consumers are unwitting victims of the tobacco industry by addressing social, physiological, and cultural aspects of smoking, and to show participants some of the forces being brought into play to control their lives in both positive and deleterious ways. By vividly revealing these forces and providing some of the facts about the dangers of cigarette consumption, participants would become acutely aware, better informed—perhaps even outraged—when they find themselves being enticed to smoke cigarettes through advertising, peer pressure, and store displays. For individuals who were already smokers, *Smoke & Mirrors* was intended to reinforce that smoking is a dangerous, expensive, hard-to-quit game, which is slowly but steadily sapping away their health and financial resources; it would also serve as an incentive to think deeply about quitting the deadly habit.

Pre-Exhibit Observation

Initially, as participants waited in line to enter the exhibit they could read a panel of text explaining the exhibit. When it was their turn to move into the exhibit space, participants received a verbal introduction to the exhibit by a Fleet Science Center exhibit interpreter who interpreted the exhibit and discussed use of the interactive tools (see Appendix A). Participants' faces were then three-dimensionally scanned (Figure 1).



Figure 1. Face scanning. A visitor's face being digitally scanned through an oval cutout in the wall. The scanned face was transmitted to one of six computer kiosks that comprise the exhibit space. Copyright (2002) by Sheldon Brown. Reprinted with permission.

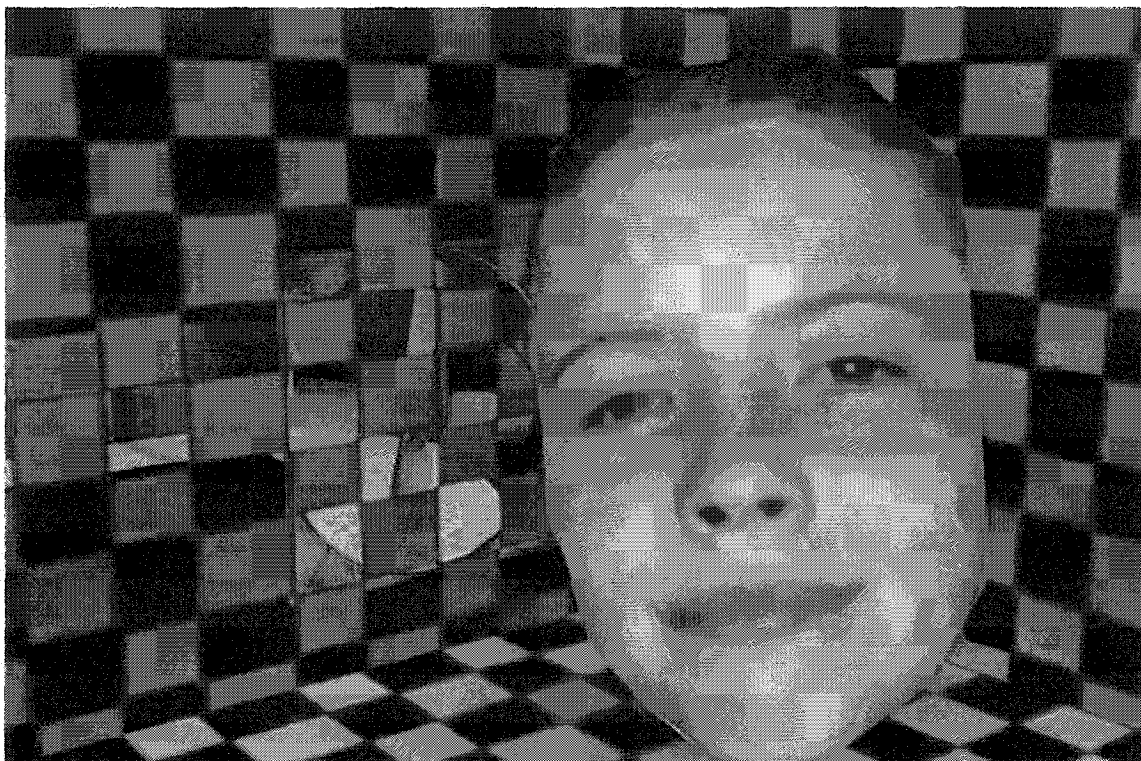


Figure 2. Scanned face on the kiosk screen. Copyright (2002) by Sheldon Brown.

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Exhibit Observation

Upon entering the exhibit, participants had to locate their previously scanned face, which was floating in the center of one of six individual kiosk screens (Figure 2). Once participants located their image at the kiosk, participants had to indicate their presence by pressing a *button* on the kiosk console. The button initiated the exhibit experience and a brief auditory training message on use of the interactive tools positioned on the kiosk console. As two to six people could share the virtual experience, each person at a kiosk had to indicate their presence for the experience to begin.

Interactions within the computer environment took place through simple, custom-built user interfaces, such as the *joystick* and *trackball* tools (see Figure 3).

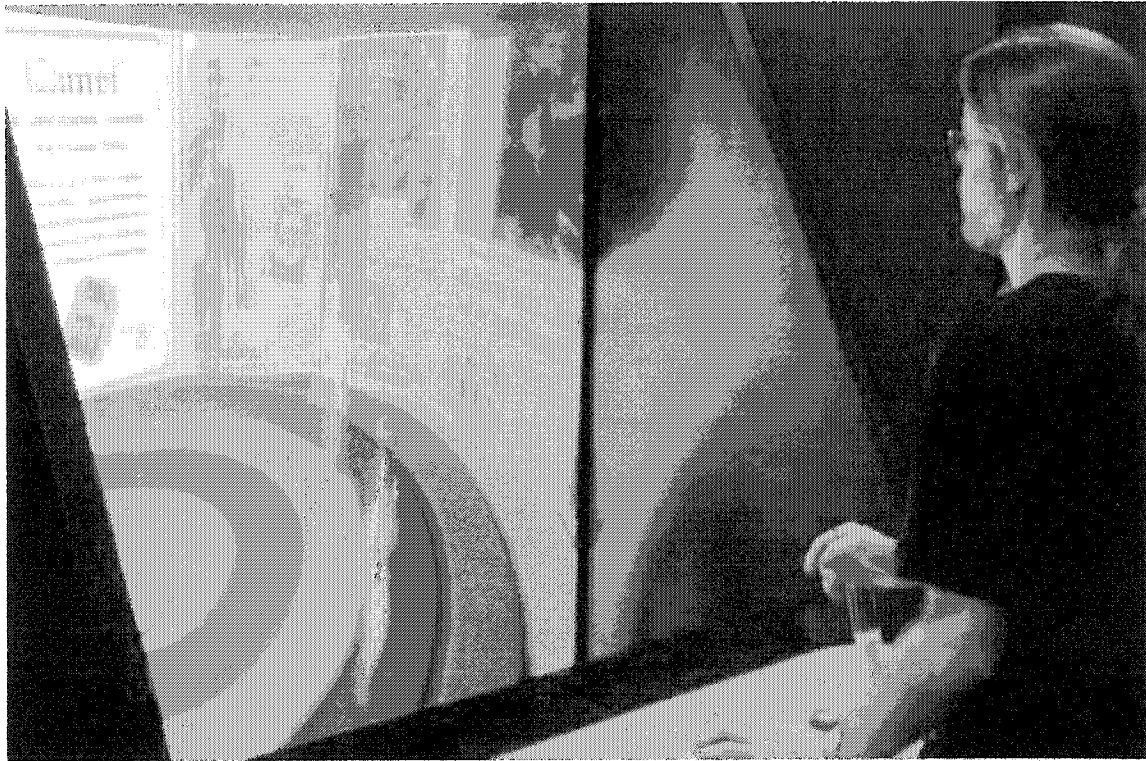


Figure 3. Kiosk station. The *Smoke & Mirrors* kiosk is shown with a participant at the viewing screen (7 x 5) with his right hand on the interactive *joystick*. The visual image on the screen is one of the exhibit's virtual environments. Copyright (2002) by Sheldon Brown. Reprinted with permission.

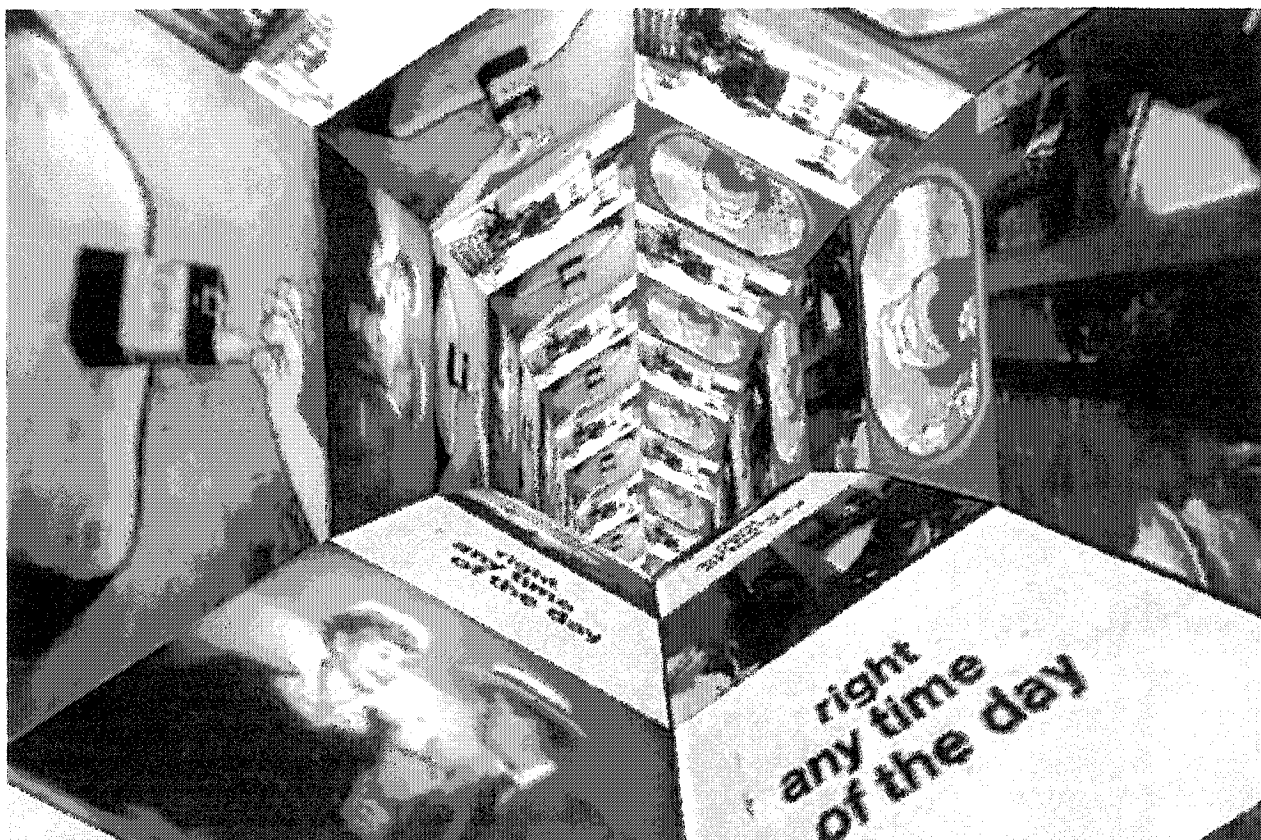


Figure 4. 3D tunnel. Participant's face travels through a colorful 3D tunnel with images and auditory narration on its way to becoming affixed to an avatar's body. The 3D tunnel created the illusion of depth in the virtual experience. Copyright (2002) by Sheldon Brown. Reprinted with permission.

When all participants indicated their presence by pressing the *button* on the kiosk, the VR experience began with the participant's face swirling through a colorful 3D tunnel (Figure 4) with music and auditory content messages until the face became affixed to a virtual body—a computer-generated persona called an *avatar*, which was visible on the screen (see Figure 5).

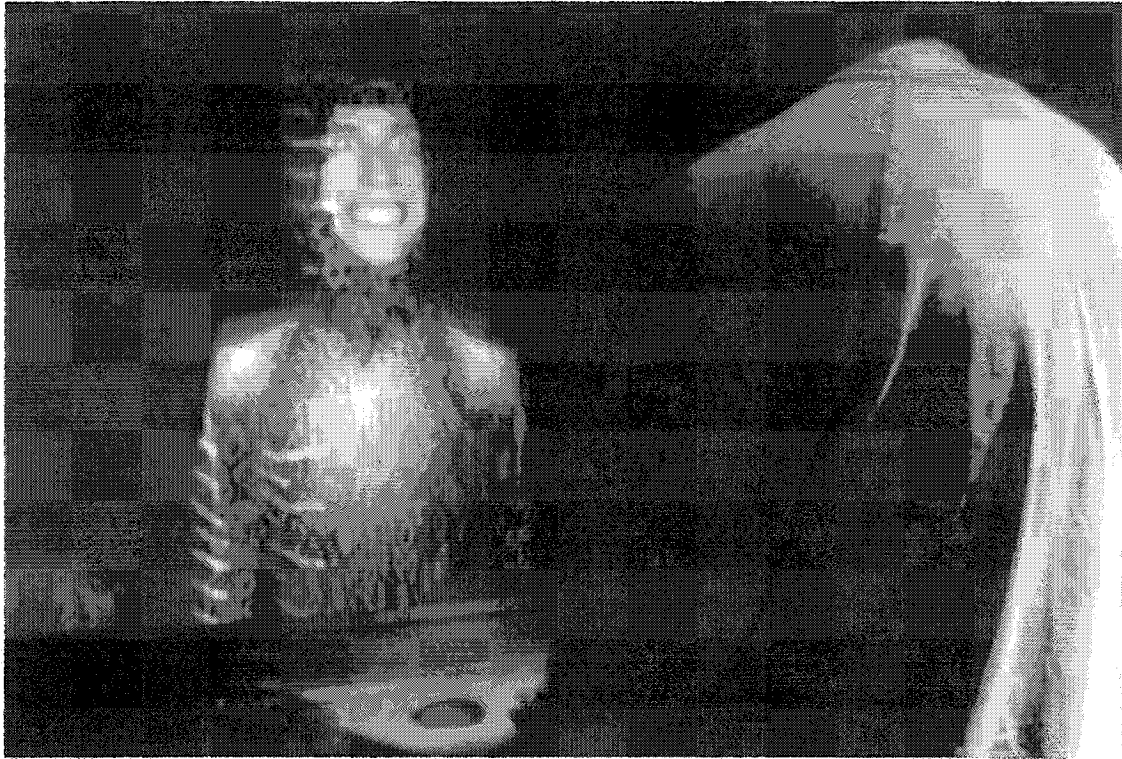


Figure 5. Face affixed to an avatar. A digitally scanned face is shown affixed to one of six avatar bodies. The button that activates the virtual experience is at the foreground of the photo. Copyright (2002) by Sheldon Brown. Reprinted with permission.

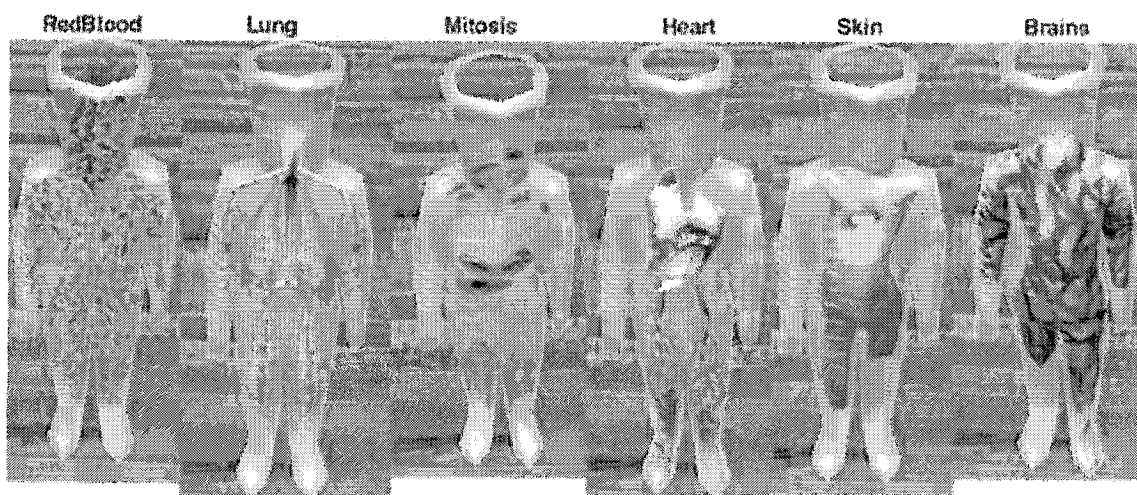


Figure 6. Six avatar bodies. Participant's face becomes affixed to one of six avatar bodies shown in Figure 6. Each avatar is constructed of a different transparent biological system of the human body. Copyright (2002) by Sheldon Brown. Reprinted with permission.

Immersed in shifting visual images and auditory messages of tobacco advertisements and cigarette usage, participants used the interactive tools to navigate their avatar body through a series of mazelike virtual environments where other avatar bodies were also observed navigated through the environment. Each of the changing virtual environments presented new visual images and auditory content messages, such as those shown in Figures 7 and 8.

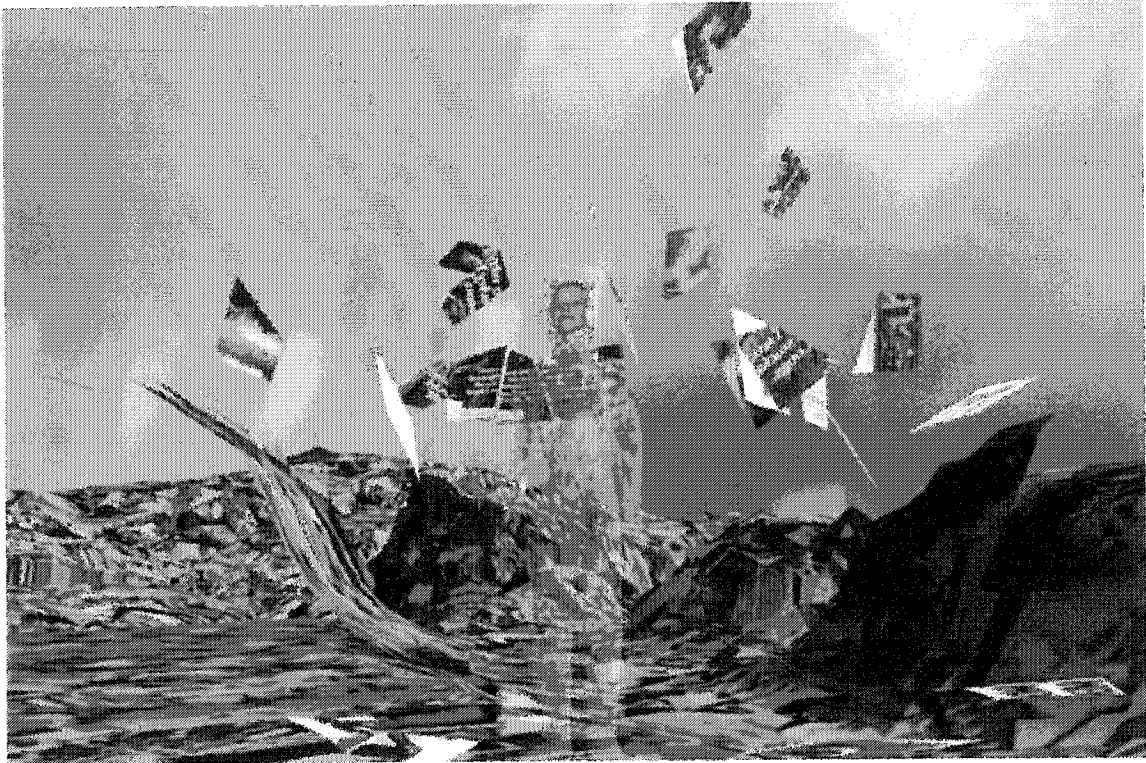


Figure 7. Garbageland. The avatar is seen navigating through *Garbageland*, a virtual environment filled with mountains of discarded and falling images of cigarette advertisements, along with auditory content messages and music. Some cigarette advertisements could be read as participant moves the avatar through the environment. Copyright (2002) by Sheldon Brown. Reprinted with permission.



Figure 8. Carousel. The avatar navigates through a spinning carousel of cigarette advertisements from old magazines, including advertisements with pictures of former movie stars, legible text, and an auditory background of music and statements from radio and TV cigarette ads, such as “You’ve come a long way baby.” Copyright (2002) by Sheldon Brown. Reprinted with permission.

Results of Post-Exhibit Interviews

The following describes the results of participant post-exhibit experience interviews. Findings are based upon transcribed audiorecordings and written interviews, observations. Themes were identified to differentiate the causal characteristics and influences of VR that enhanced and detracted from learning at the exhibit.

Effect of Staff Instructions

Interviews, observations, and audiotapes were transcribed and themes identified. Data indicated value in providing instructions to participants by Fleet Science Center staff prior to the exhibit experience, with 9 out of 14 participants stating they found the staff instructions useful. However, 13 out of 14 participants spent all, most, or part of their time trying to figure out what to do during the exhibit because staff instructions were difficult to implement within the exhibit's virtual environment.

Statements, such as “What I was told the exhibit was about by staff was different from what the exhibit did,” and “I would have walked out of the exhibit and wondered what the exhibit was about if it had not been explained to me beforehand” portray the essence of participant comments.

Effect of Age-Range and Gender

Interviews, observations, and audiotapes were transcribed and themes identified. Data showed no difference in gender learning, and one area of difference in age-range on learning. Findings revealed that 12 out 14 participants had problems using the interactive tools across all age-ranges, however the 47 and above age-range all attributed problems with using tools to a lack of age-related competence; age-ranges below 47 were split—attributing problems with using tools to both a lack of competence and faulty tools. No other data revealed gender or age differences; therefore research findings are presented as the aggregate of both genders and all age-ranges of participants in the study.

Effect of Audio Narration

Interviews, observations, and audiotapes were transcribed and themes identified. Data indicated that auditory narration had a significant effect on the exhibit experience, both enhancing and detracting.

Auditory narration was a consistent feature of the exhibit experience, beginning with requests to the participant to press a button on the kiosk to initiate the experience, and continuing with content messages associated with the visual imagery throughout. Participants preferred narration that used familiar statements from their lives, such as “*You’ve come a long way baby,*” from TV commercials targeting and recruiting female smokers.

Detracting factors included the narrator’s fast-paced content delivery, and voice and speech clarity. Participants expressed difficulty differentiating the narrator’s speech within the context of repetitive background music. Narrator’s vocabulary was indicated as too sophisticated, especially for younger ages. Other less mentioned themes included the exhibit’s overall virtual environment, colors, and music.

Statements, such as “I didn’t know what it [narrator] was talking about”; “Vocabulary words were esoteric and didn’t connect to the actual experience”; and “I would rather pay attention to environment than what was being said by the narrator” portray the essence of detracting participant comments. Table 3 shows characteristics that affected the quality of narration in order of the most detracting.

Table 3

Detracting Characteristics Effecting Narration	
Themes	No. Responses
Visuals, music, and narration presented at same time	10
Visuals (pictures and avatar)	8
Voice and speech clarity	7
Speed of verbal instruction	6
Vocabulary	5
Music	4

Effect of Sound and Music

Interviews, observations, and audiotapes were transcribed and themes identified. Data indicated that the music went unnoticed by some participants, and of those that were aware of the music, music had an effect on learning.

Twelve out of 14 participants had no problem with the sound level; some considered the music as a neutral factor, paying little to no attention to it. Participants preferred music that had some degree of familiarity from TV commercials or radio.

Statements such as, “Was there music?” and “My attention was on struggling with tools, so music was tuned out” portray the essence of participant comments.

Participants, who considered music a noticeable part of the experience, considered it a detracting factor. Detracting factors were: the music was disconnected and dissonant from the experience; too loud and repetitive; and added confusion to the constantly changing visual experience. Statements, such as “The music didn’t bring me into the

experience” and “it was pounding and relentless” summarize detracting comments. Table 4 summarizes detracting themes.

Table 4

Summary of Detracting Characteristics of Music
Detracting Themes

Caused dissonance from experience

Too loud and repetitive

Added confusion to experience

Effect of Visual Images

Interviews, observations, and audiotapes were transcribed and themes identified. Effects of visual images on learning are discussed in three parts: the *avatar*, *pictorial content*, and *movement of images*.

In Figure 5, the avatar’s virtual persona with participant’s face was intended to personalize the avatar and virtual experience. Relationship was established with the avatar as participants navigated *their virtual body* through changing environments.

Data indicated that the avatar detracted from learning with 10 out 14 participants. Interactive tools used for navigation were unresponsive, inhibiting participant-directed movement of the avatar within the virtual environment, which resulted in decreased personalization of the avatar. Participants commented that they could not experience the avatar as themselves because the avatar did not respond according to their personal preferences. The virtual persona of the avatar, even with the participants face, was

experienced as too mechanical and unrealistic to be experiences as a personal representation of the participant.

Statements, such as “The experience would have been just as powerful without the avatar”; “Looking through the eyes of a virtual character is far more effective than seeing your face in the distance on a virtual body”; and “The avatar wasn’t moving through environments in order to do something or get somewhere” portray the essence of participant comments.

Table 5 shows a summary of the avatar’s enhancing and detracting characteristics.

Table 5

Summary of Avatar's Detracting and Enhancing Characteristics

Themes	Enhancing	No. Responses	Detracting	No. Responses
Personalization of the avatar	Participant's face on avatar increased personalization of experience.	4	Participant's face on avatar was meaningless; body too unrealistic	10
Role of avatar	Avatar was only interactive element to control and explore the virtual environment.	2	Participants unclear of the avatar's role; did not find its presence useful in learning.	12
Value of avatar on learning	When tools controlled avatar, there was increased sense of immersion	2	Unresponsive tools controlling avatar distracted and thwarted learning.	12

The exhibit's virtual environment was filled with realistic and unrealistic images and changing pictorial environments. Realistic images, because of their familiarity in participants' lives fostered feelings of immersion in the environment; increased participant comfort; and were sources of learning indicated by participants in the exhibit. Realistic images such as a laboratory, magazine advertising (see Figure 8), and convenience store (Figure 9), were preferred over unrealistic images.

Participants disliked the use of unrealistic imagery, such as *Garbageland* (Figure 7), and considered those images as presenting an alien, lonely, and cold environment that participants didn't want to engage in.

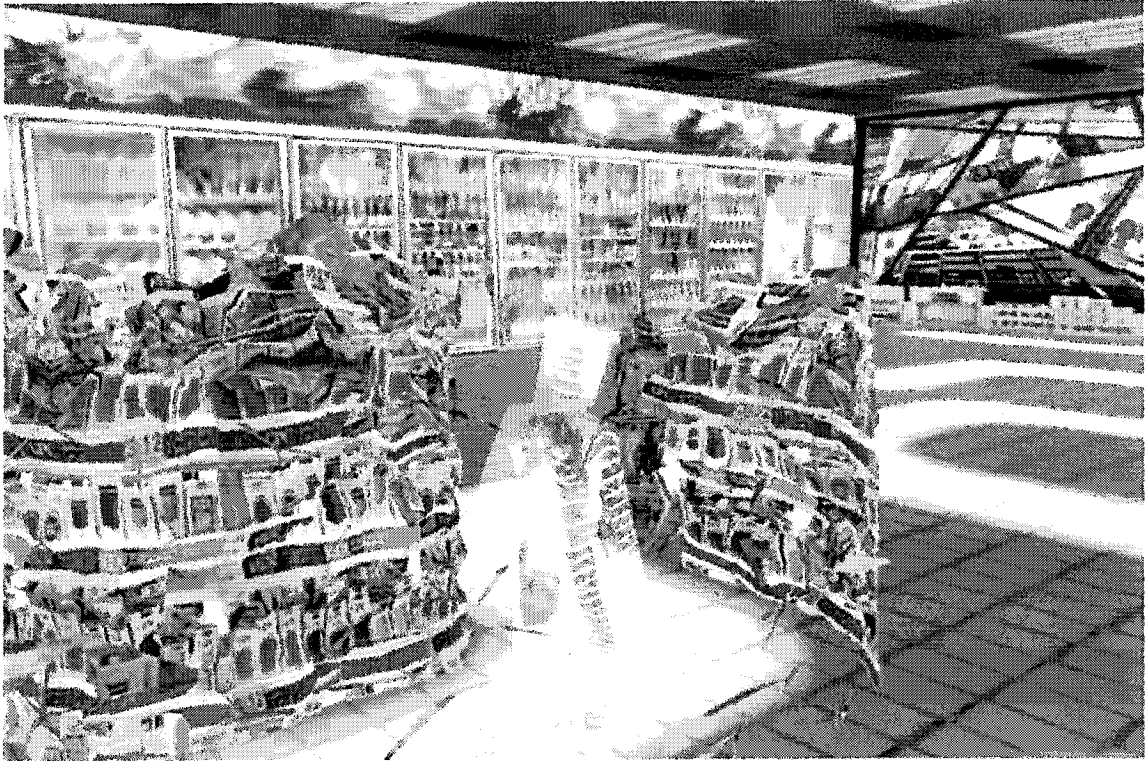


Figure 9. Convenience store. The avatar is seen navigating through a *convenience store* where it must avoid becoming a victim of the tobacco industry's product placement.

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Statements, such as "I thought the environment was so unrealistic that even with my face on the avatar I couldn't see myself in that space" and "I felt immersed—but it was a feeling of being trapped" summarize participant comments.

Constant change of the visual environment (excluding the avatar) had the *most detracting effect on learning*. Specific images, such as the *3D Tunnel* (see Figure 4) enhanced learning by increasing feelings of immersion in the environment. Participants

also indicated overwhelming feelings of dizziness, nausea, and disorientation throughout their experience due to swirling bright colors (Figure 10), constantly changing visual scenes, and new navigation scenarios.

Statements, such as “I felt a sense of motion sickness and dizziness” and “There is so much going on through the whole thing that you can’t get the whole picture,” portray the essence of participant comments.



Figure 10. Color wheel. The bright, spinning *color wheel* of advertising images shows the avatar navigating through the virtual experience. Copyright (2002) by Sheldon Brown. Reprinted with permission.

Table 6 summarizes participant comments on the effects of image movement; realistic versus unrealistic pictorial images and environments; images with text; colors; and image quality—presented in order of highest number of participant comments.

Table 6

Detracting and Enhancing Visuals in the VR Environment^a

<i>Themes</i>	<i>Detracting</i>	<i>Enhancing</i>
Image movement	Moving images and changing visual environments were distracting, confusing, and overwhelming.	Some movement of images increased sense of immersion.
Realistic vs. unrealistic pictures and environments ^b	Unrealistic visual elements of the virtual environment caused disorientation, fear, and discomfort in participants.	Realism had a positive effect on participant enjoyment, learning, and exploration of the environment.
Images with text	Images with text moved too fast for participants to read.	Images containing text were found interesting to participants.
Image colors	Colors were too bright and harsh for a large kiosk screen.	
Image quality	Images appeared blurred and hard to view.	

^aVisuals other than the avatar.

^bRealistic images were the only identified sources of learning in the exhibit.

Statements, such as “It is hard to learn serious content in a make believe environment,” and “I had questions but couldn’t learn on my own [*sic*]” summarize participant comments.

Effect of Interactive Tools

Interviews, observations, and audiotapes were transcribed and themes identified. The *Smoke & Mirrors* kiosk displayed three interactive tools: a *button*, *joystick* and *trackball* (see Figure 3). Of the three tools, only the *joystick* and *trackball* were operative for navigating the avatar through the virtual experience.

The virtual environment was very busy with changing visual environments and auditory messages, often experienced as chaotic. The use of interactive tools, according to one participant, “added more unwanted input.” Participants expressed self-doubt about their competence in tool use despite their prior experience with interactive tools in computer and video games.

In addition, participants desired, but couldn’t achieve self-directed learning, as the tools were too difficult to learn and control as the experience progressed, which resulted in participants believing that they had missed learning opportunities. Participants used interactive tools in a hit or miss manner trying to figure out how the tools worked and how to receive information. Thirteen participants spent *all* (4), *most* (5), or *part* (4) of their time figuring out how to use the interactive tools instead of focusing on the content and virtual experience.

A push-button initiated the exhibit experience. Although the button was placed prominently next to the other two tools on the kiosk console, the button was used only once during the experience. However, participants assumed because it was prominently

placed, it served additional functions; therefore participants kept randomly pressing the button throughout their experience hoping to initiate interaction. Although the button was only for initiating the virtual experience, the exhibit began on its own without pressing the button. This caused participants to question whether the experience was activated, as the exhibit was progressing.

The objective of the trackball was to change participant's view of the environment. Participants could rotate the trackball to get a birds-eye view of the environment, look up from the ground, or scan the environment from left to right. Participants were observed spinning the trackball over and over in frustration, and questioning what the tool was supposed to achieve. The tool was delayed in responding and difficult to control; therefore many participants were unable to benefit from seeing different views of each virtual environment, which may have negatively affected learning. Of the few participants who were able to use the trackball effectively, and observe the virtual environment from different perspectives, it was stated as the *most positive experience* of all the interactive tools.

The objective of the joystick was to control the avatar's walking movements—right and left, and back and forth. The joystick was easy to move but counter-intuitive; pushing forward moved the avatar in reverse, and conversely, pulling in reverse moved the avatar forward. The avatar's movements were, in addition, not often in sync with the joystick. The avatar navigated through the virtual environment on its own without directive from participants. When participants did operate the joystick to direct the avatar's movement there was often no response; therefore, most participants found

the joystick difficult to use and control, and experienced navigation as frustrating and purposeless.

Statements, such as “If the goal was to make people frustrated then the tools worked” portrays the essence of the effect of interactive tools. Other statements, such as “I would have preferred no tools to the ones that were there, as they had no effect and no purpose” and “I could not enjoy the exhibit experience because it was too hard to figure out how to use the joystick and other things” are confirming of the issues.

Content Learning

Interviews, observations, and audiotapes were transcribed and themes identified. Participants consistently stated that exhibit content was *learned*; although upon inquiry participants confirmed that the content had already been learned through prior experience. When queried if *new* information had been learned, 5 out 14 participants stated they had learned new content; 8 didn't learn anything new; 1 was unsure.

Tables 7-9 summarize information participants stated they learned newly, and parts of the exhibit that were the stated agents of such new content learning.

Table 7

Types of Information Learned

Themes

New understanding of how product placement is used in convenience stores to distract consumers and encourage them to purchase unneeded food products and cigarettes.

New understanding of how smoking was portrayed in the media as glamorous and positive, and part of being a patriotic American.

New understanding of the link between smoking and advertising.

New understanding of the deleterious effects of smoking on the body.

Table 8

Parts of Exhibit Where Learning Occurred

Themes

Medical laboratory displaying body parts effected by smoking

Convenience store with realistic products

Magazine advertising with familiar people and statements

Table 9

Characteristics That Facilitated Learning

Themes

No.

Responses

Visuals

7

Auditory Narration

6

Interactivity with tools

3

Text on images

2

Avatar

1

Emergent Themes

Immersion is a critical defining characteristic of VR. Research findings revealed characteristics of the VR exhibit that effected participants' sense of immersion in the exhibit learning experience.

Exhibit immersion. Interviews, observations, and audiotapes were transcribed and themes identified. Participants who did not navigate well through each of the virtual environment scenarios stated they experienced being trapped in the environment. Although being trapped was communicated as a negative reaction, it was found that such experiences also created a powerful, albeit disconcerting sense of immersion. Participants expressed an emphatic desire to withdraw from some of the scenarios. Unrealistic visual environments, such as *Garbageland* (Figure 7), were found to disassociate participants

from the VR experience because participants couldn't identify with the pictures. The *Carousel* (Figure 6) and *3D Tunnel* (Figure 8) were found to create feelings of immersion in the virtual experience because the perpetual spinning of those images and the 3D affect created depth and movement that drew participants into the experience. Other visual images moved or changed too frequently to produce any connection or sense of immersion, according to participants.

Conflicting data. Although 11 participants visited the Fleet Science Center for entertainment and 3 for education, responses from all participants indicated an emphatic desire for the exhibit to have been more educational. Future research studies might investigate the conceptualization of science education in the minds of new audiences.

Chapter Summary

Research investigated the effects of Virtual Reality (VR) on learning at the *Smoke & Mirrors* science exhibit at the Reuben H. Fleet Science Center in San Diego, California. Findings differentiated the causal characteristics and influences that enhanced and detracted from participant learning, discussing the interplay between the exhibit's pictorial elements, moving images, sound, narration, interactive tools, and other emergent influences of the exhibit's VR instructional design. Results showed the VR exhibit had several positive effects on participant learning; however, those results indicated that learning was exclusive to realistic pictorial elements, and of those that learned new content, it was only a low percentage of participants.

Conversely, research revealed significant detracting characteristics and influences. Detracting characteristics were predominately associated with high cognitive load, lack of established presence, and unclear instructional design. Other contributing

factors played a role in diminishing participant learning. Chapter 5 presents research conclusions, recommendations for future research, and recommendations for the future design and implementation of VR exhibits at informal science centers.

Chapter Five: Conclusions and Recommendations

The study investigated the effects of Virtual Reality (VR) on learning at the *Smoke & Mirrors* science exhibit at the Reuben H. Fleet Science Center (Fleet Science Center) in San Diego, California. Research focused on the interplay between the exhibit's pictorial elements, moving images, sound, narration, interactive tools, and other emergent influences of the exhibit's instructional design. Inquiry differentiated the causal characteristics and influences that enhanced and detracted from participant learning. Recorded interviews and observations of 14 participants (six females and eight males) were conducted in April 2004.

Case study methodology was employed utilizing visitor observations and interviews to collect data on participant reactions to the exhibit. Collected data consisted of written and audiorecorded observations of participants at the exhibit, and written and audiorecorded interviews at the conclusion of the exhibit experience. Data analysis included transcription of written and recorded data, and triangulation of data with exhibit documents, reports, and discussions with the Fleet Science Center. A prior, brief mixed methods evaluation of *Smoke & Mirrors*, conducted in 2003 by Thomas Kiefer Consulting contributed background to this investigation and its implications and strategies.

Investigation of *Smoke & Mirrors* was driven by two research questions. Each will be discussed in light of data analysis and findings. Findings will directly inform the design of a new VR exhibit at the Fleet Science Center, and contribute to the effective use of VR in exhibits at informal science centers.

Conclusions

Two research questions guided the study's inquiry of the *Smoke & Mirrors* exhibit. In response to question one, "What characteristics and influences of the *Smoke & Mirrors* exhibit were shown to facilitate learning," the following subareas were investigated: a) effects of navigational strategy, b) effects of visual elements, c) effects of sound and narration, and d) effects of interactivity.

Exhibit Characteristics Facilitating Learning

Table 10 summarizes findings on the characteristics and influences shown to facilitate new content learning. As indicated in Table 10, *familiarity* with pictorial images and statements from historical cigarette advertising ads, influenced learning.

Table 10

Summary of Characteristics Facilitating Learning

Themes	Effect on Learning
Narration	<i>Familiar</i> auditory statements from TV reinforced participant learning by encouraging discussion and inquiry.
Pictorial images	<i>Familiar</i> images of the Convenience Store with food and cigarette products (Figure 6), and the Carousel with magazine ads showing pictures of film and TV personalities (Figure 7), were mentioned by participants as the primary sources of content learning.

Table 11 shows similar findings by Thomas Kiefer Consulting in their evaluation report of *Smoke & Mirrors*, June 2003.

Table 11

Most Effective Parts of Exhibit^a

Participant Response

Participant face on avatar (Figure 5)

Print ad carousel (Figure 8)

Garbageland (Figure 7)

Convenience store (Figure 9)

Autopsy table

^aFindings of the Thomas Kiefer Consulting evaluation in 2003.

Although familiarity with realistic images was not discussed in the Kiefer Consulting evaluation, participants stated realistic images as the most effective part of the exhibit, consonant with current findings. Images with text, such as of old cigarette advertisements in magazines (Figure 8) attracted participant attention. Participants were curious about the text on the image; therefore, those images became sources of new content learning. Gibson (1979) suggests that words can be understood more easily than pictures, even easier than well-known pictures, and that words plus pictures are the most comprehensible to learners. McManus (1989) suggested the importance of interactive text in attracting learner attention, and that such attracting power can contribute to exhibit holding power. This would account for, at least in part, the appeal of such image types in *Smoke & Mirrors*, and the strength of these images as learning objects given their ability to attract and sustain participant attention.

The Kiefer evaluation also reported (see Table 11), that the participant's face on the avatar was an effective part of the exhibit. Those results conflict with findings in this study, where 10 out of 14 participants stated the face on the avatar did not assist them in learning. Participant statements, such as "It made no sense to see one's face on the avatar"; "My face was not in sync with the body"; "I couldn't tell which way my face on the avatar was facing"; "The face said it was me, but I couldn't act like myself," and "I was inclined to just ignore the avatar," summarize the essence of participant comments.

The Kiefer evaluation and the findings of this study both point exclusively to *realistic pictorial images* as the primary facilitating source of learning. Why realism, and not the abstract pictorial elements? Perhaps the issue of *familiarity* may shed some light on participant selection. The virtual environment of *Smoke and Mirrors* was viewed by some participants as "chaotic and abstract," and "relentless," in its fast-paced auditory narration, music, changing visual scenes and scenarios, and interactivity. "Nothing in that world made sense" according to a participant, referring to the environment, while others found it "alien and disorienting." If nothing in the virtual environment made sense, and elements were perceived as chaotic, participants would naturally gravitate towards realistic and familiar virtual objects—elements that were comforting. To some degree, realistic images may have become invariant properties, properties that were perceived by participants as remaining unchanged from real life to the virtual world, contributing again, to the effect of grounding the virtual experience.

Image familiarity may have played an additional role in appealing to participants. Abstract environments have no inherent meaning; they evoke the subconscious. The alien and disoriented feelings experienced by participants in *Smoke & Mirrors* were real, and

in other contexts could be intensely frightening. The powerful aspect of VR is that it can simulate reality, and by doing so, provide learners with heightened experiences. Of the many experiential benefits of VR, two are that it can provide immersive virtual experiences commonly unavailable, such as spaceflight, and its immersive capacity can produce emotional or psychological effects on learners. However, if not designed appropriately, such effects can be devastating on learners. Even in the limited 7-minute experience of *Smoke & Mirrors*, a participant experienced the environment as “cold and isolating” and didn’t want to engage in further interaction. Virtual experiences by definition are immersive physically, perceptually, and psychologically. Placing learners in situations where they are *strangers in a strange land* can have serious repercussions, especially considering participants who are unable to navigate through frightening environments successfully. As in *Smoke & Mirrors*, participants felt trapped and inadequate as a result of not being able to successfully navigate through the virtual experience and have a sense of control over the experience. Combining fear with failure can result in a powerfully negative psychological experience for some learners.

Exhibit Characteristics Detracting from Learning

In response to “What characteristics and influences of the *Smoke & Mirrors* exhibit were shown to interfere with, or detract from, learning” the following subareas were investigated: a) effects of navigational strategy, b) effects of visual elements, c) effects of sound and narration, and d) effects of interactivity. Summary of the exhibit’s most detracting characteristics can be found in Table 12.

Table 12

Summary of Most Detracting Characteristics

Themes	Effect on Learning
Interactivity and navigation	Problems with tool usability and design affordances created high cognitive drain on participants and poor learner attention. Self-directed learning and exploration within the environment was thwarted.
Movement of imagery ^a	Frequent changing of pictorial images, scenes, and scenarios caused physical discomfort, disorientation, and confusion.

^aMovement of visual images was found to be the most detracting characteristic of the virtual experience.

Use of media. Data showed that 11 out of 14 participants expected movement of visual images to be an essential characteristic of the virtual environment. However, movement of visual images was found to be the most detracting characteristic of the virtual experience. An explanation of the problem may be found in the design of the movement itself.

Participants were overwhelmed by the exhibit's high-sensory environment with perpetually changing visual scenarios and pictorial images—some realistic, and others with swirling visual patterns in bright primary colors (see Figure 10); background music was loud and repetitive; juxtaposed, was an overlay of fast-paced auditory narration with content messages. Interactive tools were in constant use with participants struggling to

navigate the avatar—the virtual persona of the human body—through the changing visual and auditory environment. Such sensory overload in the environment produced physical reactions in participants: stress, disorientation, confusion, nausea, and dizziness. The environment had many elements competing for participant attention. Sweller (1988), suggests that content learning cannot be effective when it's combined with high levels of interactivity among elements because difficulties in processing information can occur when the learner has to focus attention on too many different elements at the same time.

Sense of presence. The term *cognitive presence* (Bricken, 1990a; Sweller, 1988) has been used synonymously with the term *immersion* and it distinguishes VR from other types of computer applications because its effect can affect the authenticity of the virtual experience and self-directed learning (Zeltzer, as cited in Winn et al., 2002). Case in point is *Smoke & Mirrors* where the designer limited participant interaction within the virtual environment. The absence of self-directed learning resulted in reduction, if not elimination, of participants' sense of presence. Given that all participants indicated prior to entering the exhibit that they expected VR to be a highly immersive experience, participant disappointment was, accordingly, very high.

The sense of immersion that interactive games are able to provide is accomplished through the use of *control*. Increasing just the illusion of control is motivating, while decreasing player control reduces motivation (Dweck, 1975). When participants in the study indicated that they could not go where they wanted to go in the *Smoke & Mirrors* virtual experience, it created intense frustration and boredom, as well as direct thwarting of content learning. Valuable learning objects, such as pictures with text, as previously discussed, could not be accessed because the interactive tools thwarted self-directed

navigation and exploration. Participant tool control for purposeful navigation and learning is critical and might be resolved through instructional scaffolding.

Cognitive load. In the midst of high visual and auditory sensory load on participant attention, participants were required to engage in interactivity with tools. Interactive tools were used for moving the avatar—the virtual persona of a human body—through the virtual environment, which was the only interactive activity in the experience. As discussed previously, participants found the interactive tools difficult to understand and control. The cognitive demand on participants' attention while the exhibit was in progress caused 13 out of 14 participants to spend all, most, or part of their exhibit experience figuring out how to work the tools, instead of attending to learning. Park and Hannafin (as cited in Hasselbring et al., 1992) found high levels of interactivity caused high cognitive load and interfered with student learning.

If the technology interface is not easy to use, participants will not often spend their time and energy on trying to figure out how to make the tools work (Gibson, 1979). In *Smoke & Mirrors*, participants expressed that they would have left the exhibit because the technology was too confusing if they were not engaged in the research study, supporting Gibson's assertion.

Instructional design. Participants were unclear of the instructional design of the virtual experience and 50% of the participants expressed self-doubt regarding their own competence in using the interactive tools and understanding what was expected of them at the exhibit. When one approaches an exhibit, or something never used before, Norman (1988) suggests that the question "How do you know what to do?" should be answered by the instructional design. The instructional design of the elements of the experience, are

known as *affordances* (Gibson, 1977). Affordances may or may not be visible to the learner, as affordances can also allow the learner to *perceive* the possibility of an action. The result of the instructional design of affordance elements is to always facilitate the learner physically doing something. As a result, affordances play an essential role in guiding the learner through the technology experience without causing distraction. This reduces cognitive demand on the learner, and increases learners' sense of immersion in the experience. A further example of the critical nature of an exhibit's instructional design is that in *Smoke & Mirrors* the exhibit's primary *experiential objective* was to produce feelings in participants of being trapped in the virtual environment, with the purpose of associating those feelings with feelings of being trapped in real life by cigarette product placement in stores and a deluge of persistent cigarette advertising. Not one participant related their frustration with the exhibit experience to such a message. When the purpose of the limited interactivity was clarified after the research concluded, participants reacted more favorably to the exhibit because they could *make meaning* of the experience through intervention. Such meaningful intervention could be achieved as part of the exhibit experience through the design of affordances and scaffolding.

Instructional challenge. The exhibit's virtual experience did not have instructional complexity, such as activities proceeding from simple to more complex, which left participants bored and frustrated. Csikszentmihalyi (1995; 1998) argues that an optimally challenging activity relies on balancing the demand of the activity with the learner's ability to perform that activity. Conversely, discouragement, frustration, irritation, and anger can emerge when *uncontrollable* and repetitive annoying events occur in technology applications, and when activities are required of a learner that cannot

be accomplished. The statements, “I thought I missed something in the experience, something important, because I was not able to do very much in the experience,” and “With virtual reality I thought I would be able to make things happen and do different types of tasks in each environment,” represent participants’ awareness of the lack of complexity and desire for more challenging experiences.

Recommendations

Virtual Reality has evolved considerably over last two decades. Its technological capability is dazzling in its diversity and complexity of formats. Although still maturing as a technology, implications for its future as a tool for education, science, medicine, and other fields, seems certain. Where VR seems to be most challenged is in the realm of providing cognitive complexity in the virtual environment. Future research and development efforts on VR might focus on providing the learner with a more complete and enhanced experience—one that transcends the technology and focuses on the quality of the virtual imagery and the psychological aspects of the experience. To such an end, the following are recommendations for future VR exhibit development at informal science centers.

Future VR Exhibit Development at Informal Science Centers

The following articulates aspects of VR exhibit development that should be carefully scrutinized and evaluated during the exhibit-development process.

VR environments. Exploration and investigation are critical to the informal science learning process. The virtual environment, as an exhibit, must achieve its pedagogical value through strategies known to be effective in informal science programs. Those strategies emphasize minds-on investigation utilizing hands-on, experiential

learning with objects or contextually rich real environments. It is suggested that a virtual exhibit environment use those instructional strategies through interactive manipulation and investigation of virtual objects, and that environment itself has properties simulating realistic dynamics that will achieve authenticity in the scientific investigation process, with environmental feedback. Consideration should be given to creating such virtual environments for self-directed and self-paced learning, using VR's multimedia capabilities as specific enhancements to the learning process.

The issue of affordance was mentioned by McGreevy (1993), a scientist who studied the potential of VR as a scientific visualization tool for planetary exploration. McGreevy emphasized the importance of Gibson's (1977) idea that the environment must *afford* exploration in order for people to make sense of it, and that although VR differs from reality, virtual objects and virtual environments are still representations of the real world and need affordances to perceive them as real experiences.

Much consideration should be given to a multicultural learning environment. Text, visual imagery, and other characteristics of the virtual environment can have different meanings to learners with other cultural understandings. Access to translation of meanings can be built in and accessible to English language learners or foreign visitors.

Physical structure. Consideration should be given to structuring exhibits for group learning (more than one person) to allow families and adult visitors to socialize as they interact with exhibit experiences. Borun et al. (1998) suggest that even though families are the primary audience for science museums, many exhibits are designed exclusively for individual users. As groups come to informal science centers for social, as well as educational reasons, providing group learning, or collaborative learning

environments will increase the exhibit's holding power, and sustain visitors' interest in the learning process. Informal science centers have not been particularly effective in addressing learning in groups, and the lack of exhibit holding power can indicate success or failure of an exhibit. (Borun, Chambers, & Cleghorn, 1996; Borun et al., 1998; Hilke & Balling, 1985). Examples of successful group interaction are video and computer games.

Content learning. Engaging the learner in critical thinking and decision-making while in the virtual environment is essential to avoid instruction based upon acknowledgment of correct or incorrect responses. It is suggested that virtual exhibits integrate a mechanism for inquiry activities that are scaffolded and provide some degree of learner mentorship that will confirm learners' progress as learners ascend through levels of content complexity at their own pace. Interactivity can provide such progressive challenge if it is used as an enhancement for self-directed investigation of the environment. As an example, a learner could stop the virtual experience from progressing in order to find solutions to posed instructional problems, receive feedback, and then continue on with the learning experience progressing to higher levels of challenge. This type of exhibit experience would create interactive cognitive mapping, integrating aspects of Constructivist thinking and learning. Such a process would be flexible and adaptive to a spectrum of age-ranges, including those unfamiliar with technology interfaces. The value of this focus is that it is designed for the learner and learning, and the technology interface provide the affordances for such learning.

Csikszentmihalyi (1990) outlines five steps towards achieving optimal psychological performance relating to intellectual challenge in exhibit design. Heeter

(1993) used these performance goals to measure the outcome of an attitudinal study on a VR program called BattleTech. The steps recommended by Csikszentmihalyi are: a) set an overall goal for the exhibit, b) measure ongoing progress, c) refine challenge as progress occurs, 4) develop skills in learners to interact with evolving opportunities, and 5) keep elevating the challenge to avert boredom. These five performance-based standards can maintain focus on participant learning and positive learning experiences.

Understanding exhibit content with post-experience discussion or extension activities deserves further thought. Post-experience interpretive opportunities could be provided at a science center to provide facilitation of content as exhibit participants transition from the virtual experience. Extended learning activities can be presented online to support the exhibit's learning goals and objectives, including online virtual experiences that can build on participants' ideas and understandings. Such activities maintain connection to the science center and increase learning through reinforcement of content.

Visual imagery. Images portraying the virtual environment play an important role as a visual language. Consideration should be given to the meaning of pictorial agents prior to their use to ascertain their educational value. The meaning of images has much to do with cultural background and other factors, and those factors can enhance or detract from learning. Images produce emotional reactions and should be carefully evaluated in formative studies for learners' perceptions.

Color creates the learning atmosphere; therefore, colors of images should be evaluated for their use on large immersive screens, similar to the use of colors on

websites, with modifications available to learners for dimming the light and color intensity, as needed.

Movement of images within the environment must be judicious and purposeful, used precisely for the achievement of specific objectives. Repetitive moving and changing of images and scenes is disruptive to the learning process; too little reduces the level of challenge and immediacy important to creating challenge and immersion in the virtual experience.

Interactivity. A design of the technology interface with intuitive use of the navigational tools is suggested to provide low levels of cognitive load, allowing the learner to focus attention on the content instead of deciphering the interface. Interactive tools are best used to achieve essential effects, such as enhancing purposeful navigation and exploration of the environment and its learning objects. Affording participants views of different parts of the virtual environment and freedom for self-directed learning would make meaning of the interactive virtual experience.

Pre-exhibit experiences could help alleviate the cognitive drain on participants associated with interactive tools. To gain proficiency in tool use, a model of the tools could be displayed near the exhibit. Other recommendations include using models for staff-facilitated exhibit interpretation. Such use of models can reduce participant stress, while increasing skill competency for optimal learning experiences.

Implications for Future Research Efforts

Technology involves, among other things, the knowledge and understanding of the creative process, which we call invention and innovation. The results of creativity have historically altered how we live—the discovery of electricity being one

example—as well as altering our understanding of the Universe. Creativity, in the service of invention and innovation, has allowed us to become collectively, architects of our own dreams. As we look forward to the future, research efforts on VR will hopefully expand, allowing the potential of this technology to come to fruition for science learning, medicine, rehabilitation, cognitive psychology, and other applications.

Currently, there is very limited research evaluation of virtual reality in education. Strangman and Hall (2002) cited three research investigations from 1980-2002 of VR in K-12 classrooms. The authors concluded that findings of student enjoyment while learning in VR are commonly reported and not as yet significant; there is no certain evidence that VR provides longstanding results on learning; and there still remains a lack of definition about the contexts for which VR might be effective.

Studies are being conducted energetically in the area of rehabilitation of disabled children and adults (Riva, Wiederhold, & Molinari, 1998). Findings from these studies on rehabilitation education indicate areas of effective learning in VR that should be investigated for their generalizability to science learning and exhibits.

Expansion of Study

The current study had agreement across all ages, and found no gender differences in the use of, or in reaction to, the *Smoke & Mirrors* exhibit. Future studies with a broader range of participants could build upon these results contributing to more generalizable instructional design approaches for VR environments.

It is recommended that future research be conducted to expand on the study's critical findings associated with visual imagery and interactivity, such as the effects of types of visuals on learning; measurement of interactivity and levels of interactivity

required to enhance learning; modulation of multimedia, such as how to modulate and control audio, visuals, and interface without distracting learners.

It is recommended, as an extension of research on visual imagery, that future research expand on the emergent patterns and trends in the findings, such as the significant effects found in this study on familiar versus unfamiliar pictorial learning objects, and realistic versus abstract pictorial learning objects.

Implications of Study

Critical to the success of science centers, as learning venues, is how well public exhibits model effective strategies for learning. It is necessary, therefore, that science centers foster science education research on VR, especially since VR's use as an exhibit is currently limited. A key challenge for future science education research is focused on the difference between VR as a learning environment and instructional programs. Instructional programs, even in informal science centers, are not often adaptive and responsive to learners, given time constraints and other variables. Technologies that offer exploration of environments, without the constraints of classrooms or real environments, are most closely aligned with the fundamental model of informal science learning

Science teaching and learning. Synchronizing exhibits to the learning strengths of students, and other learners can provide unique options for self-directed learning. VR can present science content through sophisticated modeling and animations allowing users to interactively experiment, collect and interpret data, pose questions, explore new hypotheses, and analyze results of their own computer experiments. These conditions of conducting scientific inquiry within a virtual environment allow learners to progress to more difficult and sophisticated science investigation experiences at their own pace of

inquiry. VR environments can allow learners, wherever they live, to investigate the provocative questions of our time, in the footsteps of the world's foremost scientists, within virtual expeditions. Such experiences can promote improvement in learners' critical thinking and problem-solving skills through manipulation of scientific data, data analysis, and speculation of results.

According to Ault and Herrick (1991), the role of informal learning has been focused on achieving attitudinal and conceptual change through exhibits, but exhibits hold much value for use in evolving science teaching and learning. The authors encouraged teacher education programs to explore the integration of exhibit evaluation and teacher preparation in teacher preparation coursework. As a teaching tool, VR exhibits can be used to guide teachers in achieving science-learning objectives based upon mandated science content standards. Teachers who must educate students with varied academic backgrounds and abilities can use VR exhibits that integrate a range of modalities and useful intellectual strategies. Students, who may have difficulty performing in class, can have time away from teachers and peers to engage in virtual problem-solving strategies synchronized to a learner's individual pace. An exciting aspect of using VR for education is that it has the potential of providing students of all backgrounds an equal chance to succeed in the learning process.

Informal science learning. Emerging high-tech research technologies in the fields of science and medicine; rare data, such as images from satellites in outer space of other planets; images from submarines traversing the seafloor; and images and graphics simulating and modeling the human body in 3D, are now available for meaningful integration into informal science exhibits; therefore, it is imperative that science centers

learn how to effectively address multimedia technology approaches from a pedagogical perspective (Cazden et al., 1996).

We are currently experiencing another Renaissance, filled with new scientific discoveries and theories concerning life on Earth, and the origin of the Universe. Bringing these new and complex areas of discovery to the public, and making them accessible and comprehensible is the challenge of today's innovative science center. It may be viewed as ironic, that through technology, something so alien to biological life, humanity is able to observe the most intricate systems and processes of life—beyond anything we ever experienced or dreamed. As a result, technology may help us find our unique place as guardians of this planet's magnificent life forms that we know, through research and discovery, sustain our existence. Stepping into virtual worlds we can see models of life heretofore unimaginable; therefore we may gain more insight into real life by visualizing today's knowledge upon tomorrow's virtual landscape.

References

- Ainge, D. J. (1996). Upper primary students constructing and exploring three dimensional shapes: A comparison of virtual reality with card nets. *Journal of Educational Computing*, 14(4), 345-369.
- Arthur, E. J., Hancock, P. A., & Chrysler, S. T. (1997). The perception of spatial layout in real and virtual worlds. *Ergonomics*, 40(1), 69-77.
- Association of Science-Technology Centers (2002). *ASTC sourcebook of science center statistics*. Washington, DC: Association of Science-Technology Centers.
- Ault, C. R. & Herrick, J. (1991). Integrating teacher education about science learning with evaluation studies of science museum exhibits. *Journal of Science Teacher Education*, 2(4), 101-105.
- Ballard, R. D. (1992) The JASON Project: Hi-tech exploration promotes students' interest in science. *T.H.E. Journal*, 20(4), 70-74.
- Borun, M., Chambers, M., & Cleghorn, A. (1996). Families are learning in science museums. *Curator*, 39(2), 123-138.
- Borun, M., Dritsas J., Johnson J., Peter, N., Wagner, K., & Fadigan, K. (1998). *Family learning in museums: The PISEC perspective*. Philadelphia: The Franklin Institute.
- Brainerd, C. (1978). *Piaget's theory of intelligence*. Englewood Cliffs, NJ: Prentice-Hall.
- Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press.
- Bricken, M. S. (1991). Virtual reality learning environments: Potentials and challenges. *Computer Graphics*, 25(3), 178-184.
- Bricken, M. S. & Byrne, C. M. (1992). *Summer students in virtual reality: A pilot study on educational applications of VR technology* (HITL Report No. R-92-1). Seattle, WA: University of Washington. (ERIC Document Reproduction Service No. ED358853)
- Bricken, W. (1990a). Virtual reality, as unreal as it gets. *Proceedings of Directions and Implications of Advanced Computing*, 90, 265-267.
- Bricken, W. (1990b). *Learning in virtual reality* (HITL Report No. M-90-5). Seattle, WA: University of Washington.
- Brill, L. M. (1994). The networked VR museum. *Virtual Reality World*, 2(1), 12-17.

- Bruner, J. (1960). *The process of education*. Cambridge, MA: Harvard University Press.
- Casey, J. A. (1995). Developmental issues for school counselors using technology. *Elementary School Guidance & Counseling*, 30, 26-34.
- Cazden, C., Cope, B., Kalantzis, M., Luke, A., Luke, C., & Nakata, M. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, 66(1) 60-92.
- Collins, A. J., Brown, S., & Neuman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.) *Knowing, learning and instruction: Essays in honor of Robert Glaser*. Hillsdale, NJ: Erlbaum.
- Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage.
- Cromby, J., Standen, P., & Brown, D. (1996). The potentials of virtual environments in the education and training of people with learning disabilities. *Journal of Intellectual Disability Research*, 40(6), 489-501.
- Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal performance*. New York: Harper and Row.
- Csikszentmihalyi, M. & Csikszentmihalyi, I. S. (Eds.). (1998). *Optimal experience: Psychological studies of flow in consciousness*. New York: Cambridge University Press.
- Csikszentmihalyi, M. & Hermanson, K. (1995). Intrinsic motivation in museums: What makes visitors want to learn? *Museum News*, 74(3), 34-37, 59-61.
- Dewey, J. (1939) *Education and Experience*. New York: Collier Books.
- Dweck, C. S. (1975). The role of expectations and attributions in the alleviation of learned helplessness. *Journal of Personality and Social Psychology*, 31(4), 674-685.
- Faulkner, D. J. & McCluskey, J. J. (1994). Beginner's special feature: Virtual reality in the classroom. *HyperNEXUS Journal*, 4(2), 10-12.
- Flick, L. B. (1993). The meanings of hands-on science. *Journal of Science Teacher Education*, 4(1), 1-8.
- Gagne, R. (1987). *Instructional technology foundations*. Hillsdale, NJ: Erlbaum.

- Gibson, J. J. (1977) The theory of affordances. In R. E. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67-82). Hillsdale, NJ: Erlbaum.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.
- Gibson, W. (1984). *Neuromancer*. New York: ACE Science Fiction.
- Glaser, R. (1976). Components of a psychology of instruction: Toward a science of design. *Review of Educational Research*, 46, 1-24.
- Glenn, J. (2000). *Before it's too late: A report to the nation*. National Commission on Mathematics and Science Teaching for the 21st Century. Washington, DC: U.S. Department of Education. Retrieved June 10, 2004, from <http://www.ed.gov/americanaccounts/glenn>
- Hassard, J. (1992). *Minds on science: Middle and secondary methods*. New York: Harper Collins.
- Hasselbring, T., Goin, L., Zhou, L., Alcantara, P., & Musil, S. (1992). *Cognitive challenges and pedagogical opportunities of integrated media systems*. Presentation at the International Conference, Technology and Media, Division of the Council for Exceptional Children, Albuquerque, NM.
- Heeter, C. (1993). BattleTech masters: Emergence of the first U.S. virtual reality subculture. *Multimedia Review*. Retrieved on July 2, 2004, from <http://commtechlab.msu.edu/publications/files/battletechmasters.html>
- Heinlein, R. (1965). *Three by Heinlein*. Garden City, NY: Doubleday.
- Hilke, D. D. & Balling, J. D. (1985). The family as a learning system: An observational study of family behavior in an information rich setting. In J. D. Balling, D. Hilke, J. D. Liversedge, E. A. Cornell, & N. S. Perry (Eds.), *Role of the family in science literacy* (pp. 40-104). Gloucester Point, VA: Chesapeake Research Consortium, Inc.
- Hirose, M., Taniguchi, M., Nakagaki, Y., & Nihei, K. (1994). Virtual playground and communication environments for children. *IEICE Transactions on Information and Systems*, E77-D(12), 1330-1334.
- Hodson, D. (1990). A critical look at practical work in school science. *School Science Review*, 70(256), 33-40.

- Holden, G., Bearison, D. J., Rode, D. C., Rosenberg, G., & Fishman, M. (1999). Evaluating effects of a virtual environment with hospitalized children. *Research on Social Work Practice, 9*(3), 365-382.
- Inman, D. P., Loge, K., & Leavens, J. (1997). VR education and rehabilitation. *Communications of the ACM, 40*(8), 53-57.
- Jacobson, L. (1993). Welcome to the virtual world. In R. Swadley (Ed.), *On the cutting edge of technology* (pp. 69-79). Carmel, IN: Sams.
- Jason Project (1995). Voyage VI: Island earth. *Interface, 4*(4), 7-8.
- Jonassen, D. H. & Reeves, T. C. (1996). In Jonassen, D. H. (Ed.), *Handbook of research for educational communications and technology*. New York: Simon & Schuster Macmillan.
- Kappa Pi Lecture Series (1997). *John Dewey Experience and Education*. New York: Simon & Schuster.
- Kiefer, T. (2003). [Smoke & Mirrors anti-tobacco exhibit evaluation]. Unpublished raw data.
- Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.
- Lavroff, N. (1992). *Virtual reality playhouse*. Corte Madera, CA: Waite Group Press.
- Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R. E. Snow & M. J. Farr (Eds.), *Aptitude, learning, and instruction: Cognitive and affective process analyses* (pp. 223-253). Hillsdale, NJ: Erlbaum.
- Marek, E. A., Boram, R. D., Laubach, T., & Gerber, B. L. (2002). Conceptual understandings resulting from interactive science exhibits. *Journal of Elementary Science Education, 14*(2), 39-50.
- Mattoon, J. S. & Mowafy, L. (1993). Implications of learning theory and strategies for the design of synthetic environments. In S. R. Helsel (Ed.), *Proceedings of Virtual Reality*. Westport, CT: Meckler.
- Max, M. L. & Gonzalez, J. R. (1997). Blind persons navigate in virtual reality (VR): Hearing and feeling communicates "reality." *Studies in Health Technologies and Informatics, 39*, 54-59.

- McComas, J., Pivik, J., & Laflamme, M. (1998a). Current uses of virtual reality for children with disabilities. In G. Riva, B. K. Wiederhold, & E. Molinari (Eds.), *Virtual environments in clinical psychology and neuroscience*. Amsterdam: IOS Press.
- McComas, J., Pivik, J., & Laflamme, M. (1998b). Children's transfer of spatial learning from virtual reality to real environments. *CyberPsychology and Behavior*, 1(2), 121-128.
- McGreevy, M. W. (1993). Virtual reality and planetary exploration. In A. Wexelblat (Ed.), *Virtual reality: Applications and explorations* (pp. 163-197). Cambridge, MA: Academic Press.
- McLellan, H. (1995). Virtual field trips: The Jason project. *VR World*, 3(1), 49-50.
- McLellan, H. (1996). Virtual realities. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 457-487). New York: Simon & Schuster Macmillan.
- McManus, P. M. (1989). Oh yes they do!: How visitors read labels and interact with exhibit text. *Curator*, 32(3), 174-189.
- Meinhard, R. (1992). *Concept/process-based science in the elementary school*. Salem, OR: Oregon Department of Education.
- Merriam, S. (1988). *Case study research in education: A qualitative approach*. San Francisco, CA: Jossey-Bass.
- Miles, M. B. & Huberman, A. M. (1994). *Qualitative data analysis: A sourcebook of new methods* (2nd ed.). Thousand Oaks, CA: Sage.
- Muscott, H. S. & Gifford, T. (1994). Virtual reality and social skills training for students with behavioral disorders: Applications, challenges and promising practices. *Education and Treatment of Children*, 17(3), 417-434.
- NASA (1994). *To Mars via Antarctica*. Retrieved on June 20, 2004, from NASA Web site: <http://teacherlink.ed.usu.edu/tlnasa/pictures/litho/MarsViaAntarctica/>
- National Action Counsel for Minorities in Engineering (2002). Online data. Retrieved on April 3, 2003, from Web site: <http://www.nacme.org/index.html>
- National Center for Supercomputing Applications (1995). *Science for the millennium*. Retrieved on May 18, 2004, from University of Illinois Web site: <http://www.ncsa.uiuc.edu>

- Newby, G. B. (1993). Virtual reality. Pre-publication draft of a chapter to be included in the *Annual Review of Information Science and Technology*. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 457-487). New York: Simon & Schuster Macmillan.
- Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.
- Norman, D. A. (1990). *The design of everyday things*. New York: Doubleday.
- Park, I. & Hannafin, M. J. (1993). Empirically-based guidelines for the design of interactive multimedia. *Educational Technology Research and Development*, 41(3), 63-85.
- Pantelidis, V. (1993). Reasons to use virtual reality in education. *VR in the Schools*, 1(1), 9.
- Pantelidis, V. (1995). *Virtual reality and education: Information sources*. Retrieved on March 11, 2004, from Virtual Reality and Education Laboratory (VREL): <http://www.hitl.washington.edu/scivw/scivw-ftp/citations/VR-ED.html>
- Reiser, R. A. (1987). Instructional technology: A history. In Robert Gagne (Ed.), *Instructional technology: Foundations*. Hillsdale, NJ: Erlbaum.
- Resnick, L. (1987). *Education and learning to think*. Washington, DC: National Academy Press.
- Riva, G. (1998). Virtual reality in neuroscience: A survey. In G. Riva, B. K. Wiederhold, & E. Molinari (Eds.), *Virtual environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-therapist interaction* (pp. 191-199). Amsterdam: IOS Press.
- Riva, G., Wiederhold, B. K., & Molinari, E. (Eds.). (1998). *Virtual environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-therapist*. Amsterdam: IOS Press.
- Rizzo, A. A., Buckwalter, J. G., van der Zaag, C., Humphrey, L., Bowerly, T., Chua, C., et al. (2000). The virtual classroom: A virtual environment for the assessment and rehabilitation of attention deficits. *CyberPsychology and Behavior*, 3(2), 483-500.
- Rosenfeld, S. & Terkel, A. (1982). A naturalistic study of visitors at an interactive mini-zoo. *Curator*, 25(3), 187-212.
- Ryder, M. & Wilson, B. (1995). *From local to virtual learning environments: Making the connection*. Paper presented at the Association for Educational Communications Technology, San Francisco, CA.

- Shapley, K. S. & Luttrell, H. D. (1993). *Effectiveness of a teacher training model on the implementation of hands-on science*. Paper presented at the Association for the Education of Teachers in Science International Conference.
- Song, K., Han, B., & Yul Lee, W. (2000). *A virtual reality application for middle school geometry class*. Paper presented at the International Conference on Computers in Education; International Conference on Computer-Assisted Instruction, Taipei, Taiwan.
- Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.
- Standen, P. J. & Cromby, J. J. (1995). Can students with developmental disability use virtual reality to learn skills which transfer to the real world? *Proceedings of the 1995 California State University Virtual Reality Conference*. Northridge, CA: California State University.
- Strangman, N. & Hall, T. (2002). *Virtual reality and computer simulations*. National Center on Accessing the General Curriculum. Retrieved on February 20, 2004, from <http://www.cast.org/ncac/index.cfm?i=4832>
- Sweller (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257-285.
- Taylor, W. (1997). *Student responses to their immersion in a virtual reality environment*. Paper presented at the Annual Meeting of the Educational Research Association, Chicago, Illinois. Retrieved on February 11, 2004, from Human Interface Technology Laboratory (HITL) University of Washington: <http://www.hitl.washington.edu/publications/r-97-11/>
- Tobin, K. & Dawson, G. (1992). Constraints to curriculum reform: Teachers and myths of schooling. *Educational Technology Research and Development*, 40(1), 81-92.
- Trends in International Mathematics and Science Study (1995a). *TIMSS Mathematics and Science Achievement*. Washington, DC: National Center for Education Statistics. Retrieved on January 12, 2004, from <http://nces.ed.gov/timss/results.asp>
- Trends in International Mathematics and Science Study (1999b). *TIMSS Mathematics and Science Achievement*. Washington, DC: National Center for Education Statistics. Retrieved on March 9, 2004, from <http://nces.ed.gov/timss/results.asp>
- U.S. Department of Education. (1991). *America 2000: An education strategy*. Washington, DC: (ERIC Document Reproduction Service No. ED332380)
- Virtual Sites (2004). *Virtual tours of museums, exhibits, and points of special interest*. Retrieved on March 6, 2003, from <http://www.virtualfreesites.com/museums.html>

- Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.
- Windschitl, M. & Winn, B. (2000). A virtual environment designed to help students understand science. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 290-296). Mahwah, NJ: Erlbaum.
- Winn, W. D. (1989). Toward a rationale and theoretical basis for educational technology. *Educational Technology Research and Development*, 37, 35-46.
- Winn, W. D. (2002). *What can students learn in artificial environments that they cannot learn in class?* Paper presented at the First International Symposium, Anadolu, Turkey.
- Winn, W. D., Windschitl, M., Fruland, R., & Lee, Y. (2002). *Features of virtual environments that contribute to learners' understanding of earth science*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.
- Witmer, B., Bailey, J., & Knerr, B. (1996). Virtual spaces and real world places: Transfer of route knowledge acquired from maps and navigation. *Cognitive Psychology*, 14, 560-589.
- Witmer, B. G. & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, 7(3), 225-240.
- Yeo, S., Loss, R., Zadnik, M., Harrison, A., & Treagust, D. (1998). Interactive multimedia: What do students really learn? In B. Black & N. Stanley (Eds.), *Teaching and learning in changing times* (pp. 341-347). *Proceedings of the Seventh Annual Teaching Learning Forum*. Perth: University of Western Australia. Retrieved on February 10, 2003, from <http://cea.curtin.edu.au/tlf/tlf1998/yeo.html>
- Youngblut, C. (1998). *Educational uses of virtual reality*. Alexandria, VA: Institute for Defense Analyses (Document D-2128). Retrieved, July 9, 2004, from VR in the Schools: <http://www.hitl.washington.edu/scivw/youngblut-edvr/D2128.pdf>
- Zeltzer, D. (1992) Autonomy, interaction, and presence. *Presence: Teleoperators and Virtual Environments*, 1(1), 127-132.

Appendix A

Exhibit Interpreter Introduction: What is *Smoke and Mirrors*?

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Exhibit Interpreter Introduction: What is *Smoke and Mirrors*?*Interpreter Statement One*

This [*Smoke & Mirrors*] is an anti-smoking virtual reality exhibit, and it talks about how tobacco companies advertise smoking as something glamorous. About sixty years ago, tobacco companies tried to convince people through ads that whoever started smoking was going to be viewed as a tough, cool, and independent individuals accepted by all of society, yet hiding the sad reality of such a habit by stating, "...our experts found no harmful side effects."

Interpreter Statement Two

Exhibit interpreters may sometimes explain that there are three main sections in the exhibit: 1) the carousel, representing the decades of 1940s and 1950s; 2) Garbageland, represented by the 1960s and 1970s when smoking was depicted as rebellious, yet tolerable, after the surgeon general warnings; and 3) the convenience store representing the 80's to the current decade, when convenience stores are making almost one third of their profit from tobacco products.

Interpreter Statement Three

Keep in mind that this is not a science exhibit or a video game—it is artwork, presented in a virtual reality format. In just a moment your faces will be scanned and sent individually to computers. Your first task is to go around to the computer kiosks and try to find your face. Once you have found your face, stay there and follow the computer's instructions. You will be prompted to press the button. Do so, and then wait for a few seconds before the exhibit starts.

Appendix B

Permission for Use of Photographs

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5/19/04

SUBJECT: Permission for use of photographs in dissertation

I am granting Arlene de Strulle permission to use any of the 24 photographs that I have provided her for her doctoral thesis dissertation "*Differentiation of the Causal Characteristics and Influences of Virtual Reality on Learning at a Science Exhibit*", which is being submitted on or about July 6, 2004 to the institutions of San Diego State University and University of San Diego for the purposes of fulfilling the requirements of the Joint SDSU-USD Doctoral Program in Education. This permission is not transferable and only applies to this specific publication within the academic necessities of the thesis publication, and extends to only 21 copies of the thesis.

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Sincerely,

Sheldon Brown
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