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Psychological benefits and educational potential of physically immersive artificial environment pedagogy

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PSYCHOLOGICAL BENEFITS AND EDUCATIONAL POTENTIAL OF PHYSICALLY IMMERSIVE ARTIFICIAL ENVIRONMENT PEDAGOGY

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1. Introduction

For decades, research has found that interactivity in the learning process increases learner understanding, knowledge retention, and interest in the subject (Bonwell & Eison, 1991, p. 3; Prince, 2004). For the purpose of this project, interactivity is defined by four components: 1) it is a message loop (i.e. consists of a message and a response); 2) it occurs from the learner's point of view; 3) it has three outputs: content learning, affective benefits, and related effects; and 4) the messages must be mutually coherent – i.e. the response must be relevant to the initial message (Yacci, 2000).

This interactivity has been achieved through many methods including question and answer, discovery learning, and laboratory exercises. In the digital age, all of these methods have been implemented on computers across a variety of domains. Today, digital technologies allow learning to occur, in a sense, inside a computer. A simulated environment can be created that completely surrounds the learner, allowing the classroom to become any of a myriad different, otherwise inaccessible, locations, such as the bottom of the ocean, inside a carbon nanotube, or outside the Milky Way galaxy.

More importantly, these immersive environments allow for three-dimensional interactivity that has heretofore been unseen. Instead of just reading about the topology of the bottom of the ocean, learners can now explore it for themselves. Where one before could read that changing the chirality of a nanotube affects the conductive properties of the nanotube, one can now actually stand in the middle of a nanotube and witness the differences of electron flow created by chirality changes. Students could learn about the phases of the moon and planets by

studying models; now they can fly around celestial objects and watch that as their relative position to the sun changes, so too does the visible light on each object. While it may seem intuitive that such environments would favorably affect learning, little research has been done in a physically immersive artificial environment to prove the veracity of this assumption.

2. Background

2.1 Environments

For more than a decade, environments have been created that immerse a user in artificial imagery. The extent of the immersiveness has varied widely and can be distinguished by dimensionality. 2D, or an x-axis and a y-axis on a horizontal plane, is the typical display on a computer screen. 2.5D adds the z-axis, achieving the perception of physical dimensionality on a planar surface. True 3D has three physical dimensions that are populated with either real or virtual content (Furness, Winn, & Yu, 1998).

2D environments (including 2.5D) are immersive in only the content and not physicality. A well-known example of such an environment is virtual reality (VR) - technology that "is computer based and gives the illusion of being immersed in a 3-dimensional space with the ability to interact with this 3D space" (Byrne, 1996). VR is typically composed of three components: a visual display, an input device, and a position sensor. This technology was first pioneered by Ivan Sutherland in the late 1960s (Lantz, 1997). The visual display is traditionally a head mounted display (HMD) that contains a small video screen in front of each eye, on which the user sees a virtual world displayed instead of the physical world (Byrne, 1996; Lantz, 1996). The view for each eye is slightly different in order to create stereographic effects and the "geometrically correct computer generated image is displayed as a function of head rotation and

displacement" (Byrne, 1996; Lantz, 1997). To determine the head rotation and displacement, a position sensor is used to track the absolute position of the user. The data from the position sensor allows the VR system to determine and generate the position of the user in the projected virtual world on the HMD (Byrne, 1996).

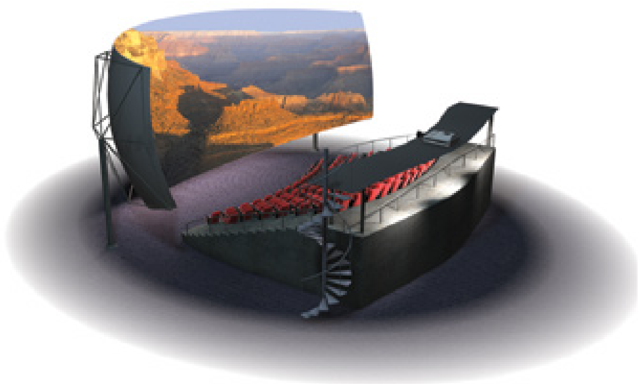

Figure 1 - ImmersaVision ("Immersive Theater Attractions," n.d.)

Other environments that could be considered immersive, but that, like VR, don't include full physical immersion, are numerous. *Armchair VR* keeps the user stationary and lets him navigate through the virtual environment (VE) using hand controllers. Instead of an HMD, Armchair VR might employ a 200º x 60º cylindrical monitor display (Lantz, 1997). A similar design, dubbed "ImmersaVision" (see Figure 1), has been designed by Spitz. The large, 200º x 80º spherical screen wraps the audience in high definition imagery and "combines the realism and power of film, with the intimacy, immediacy and value of video display" ("Immersive Theater Attractions," n.d.).

Another example of Armchair VR is the HALO system (see Figures 2 & 3), produced by Barco Simulation. It includes seamless, uninterrupted rear projection on a semi-cylindrical surface in a simulator setup, designed for uses such as flight simulations (*Barco System Solutions*, 2004).

Figure 2 Barco Simulation HALO (HALO, n.d.)

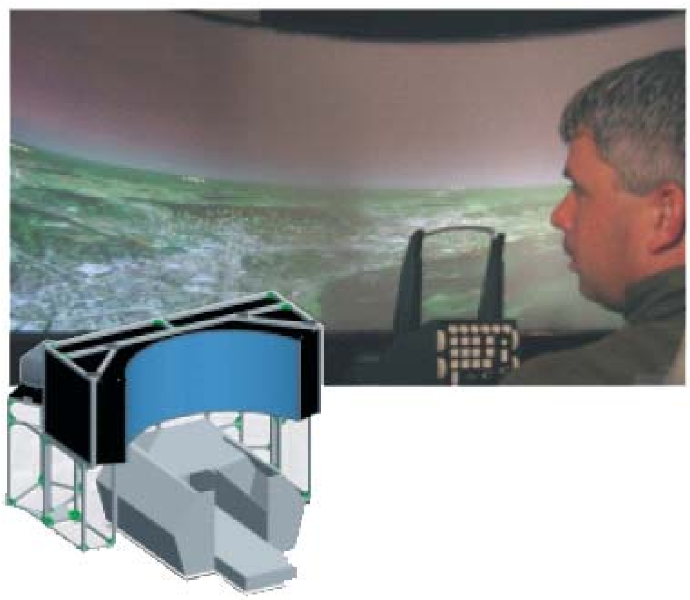

Figure 3 - Barco Simulation HALO (Barco System Solutions, 2004)

Desktop immersion is possible through using a large monitor that takes up as much of the field of view (FOV) as possible (Lantz, 1997). *Virtual model displays* (VMDs) - or "Fish tank VR" - take the idea of desktop immersion and focus it on a singular object. Due to a small displayed FOV, this environment is well suited for rendering particular objects without the surrounding virtual space (Lantz, 1997).

The term *immersive environment* has even been applied to *transactional environments,*

where multiple users can remotely communicate in a text-based setting. Examples include multi-user dungeons (MUDs) and objected oriented MUDs (MOOs), and course management systems or learning management systems. Unlike the aforementioned cases, transactional environments lend themselves to knowledge acquisition instead of knowledge construction in a contextualized environment (Lombardi & McCahill, 2004). Similarly, virtual worlds allow users to interact with an avatar in an environment that mimics the real world, with settings such as beaches and cafes, and also includes fantasy locations. Examples include WebKins, ClubPenguin, Second Life, Hobo Hotel, and Whyville. These socially driven sites often include virtual currency and economies (Goodstein, Joseph, Kafai, & Thomas, 2007).

Even when considering immersive environments with a physical element, there are many possible scenarios. IEs can just be an *involving experience*, in which participants simply spend a substantial amount of time in a physical environment that complements formal education (i.e. a science museum) or that directly provides a course of instruction, such as a week-long SAT prep course (Noel-Storr, 2004). *Spatially realistic life-sized projector-based dioramas* use spatially-augmented reality and shader lamps to combine a rough, approximate physical model with high definition projections (see Figure 4). By projecting life-like imagery onto large, standard geometric shapes constructed out of materials such as Styrofoam, one achieves augmented virtuality, auto-stereoscopic vision, and some provision of haptics (Low, Welch, Lastra, & Fuchs, 2001).

Figure 4 - Spatially realistic life-sized projector-based dioramas (Low, Welch, Lastra, & Fuchs, 2001, p.93)

2.2 Physically Immersive Artificial Environments

The focus of this paper will be on artificial environments that are physically immersive, i.e. the physical structure affords surrounding the user with projected imagery in 360 degrees (or close to it). Physically Immersive Artificial Environments (PIAEs, also known as Spatially Immersive Displays) immerse viewers in a virtual world of concrete forms (Lantz, 1996; Byrne, 1996).

2.2.1 Cyviz Vizwall

The Cyviz Vizwall includes construction better suited for discrete, surrounding images than for fully immersive environments (see Figure 5).

Figure 5 - Cyviz Vizwall (Cyviz, n.d.)

The display walls, when combined, are designed for collaborative environments in which users can view data and imagery spread across the screens. Due to the separate, isolated nature of the screens, the Vizwall is not an optimal design for PIAEs. The Cyviz projectors may include the ability for mono and stereo projection. The filters for switching between mono and stereo projection are motorized and the software for converting the digital content to stereo is platform independent. The Vizwall has a 16:9 aspect ratio, can display picture in picture, and can show two displays at once. It features 1400x1050 resolution, 6,500 ANSI Lumens, 7,500:1 contrast ratio, and a 24/7 display.

The following are all examples of environments that have been developed to allow for physical immersion in virtual worlds.

2.2.2 blue-c

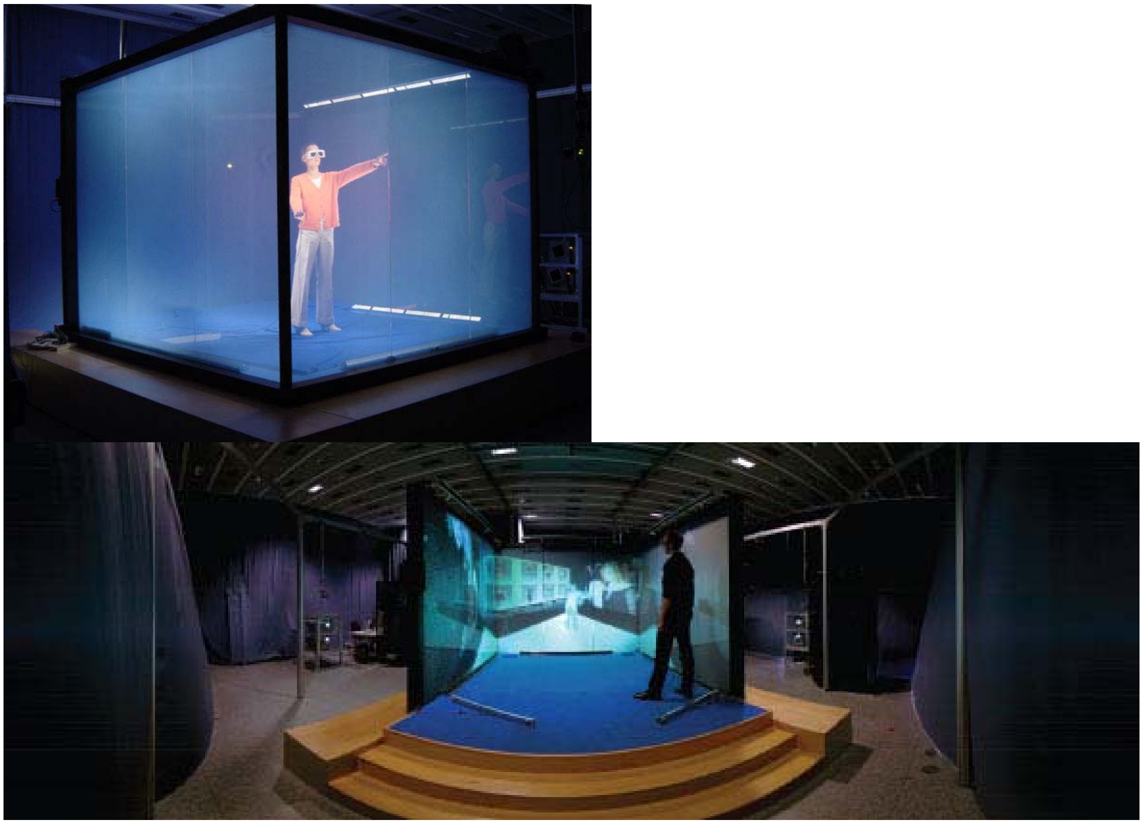

Figure 6 - blue-c (Gross, n.d.)

Blue-c is a physically immersive display and 3D video portal designed for telepresence. The walls of blue-c are constructed of phase dispersed liquid crystal (PDLC). There is a pair of projectors mounted outside each wall; the rear projection provides for no image occlusion. An array of 16 cameras records the user. The PDLC walls allow for three phases: one in which the walls are transparent so that the cameras can record the user and two others in which the walls are semi-opaque so that two slightly different images can be projected onto them. The user wears shuttered glasses that operate on a three period sequence in sync with the walls. In the first period, both eyes are shuttered so that the user does not see through the transparent walls. In the second period, only one eye is shuttered. The other eye is shuttered for the third period, allowing it to see the slightly different projection designed for stereoscopic effect. This method allows for real-time 3D projection and remote collaboration (Gross, n.d.).

2.2.3 CAVE

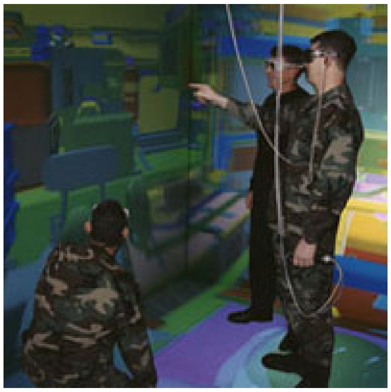

Figure 7 - CAVE (Display Systems: 3D & Advanced, 2008)

Mechdyne developed the industry-standard CAVE, which is the most popular physically immersive display. The CAVE is a room-sized structure that can have four (three walls and a floor), five, or six (which includes the ceiling) displays. It allows for high resolution (up to one million pixels), stereoscopic, 3D computer graphics which afford a complete sense of presence.

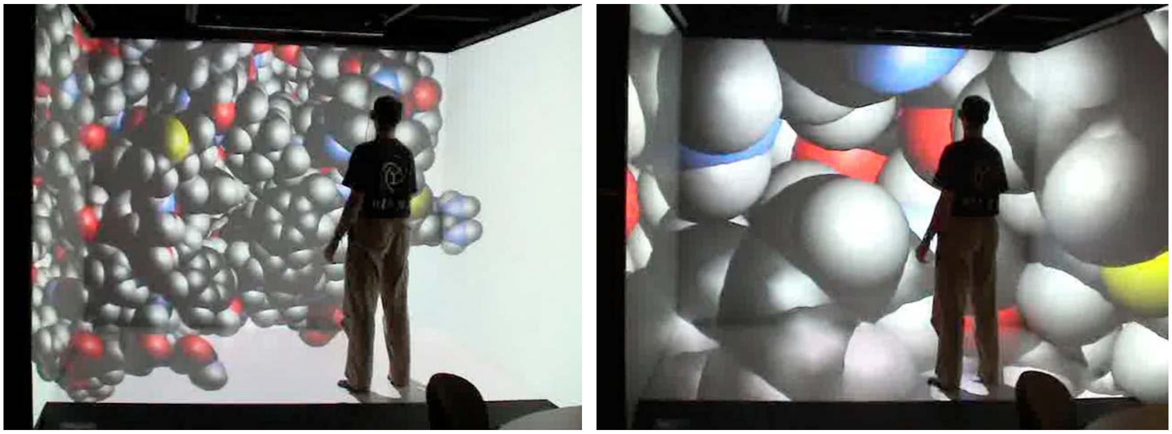

Figure 8 - CAVE (Interactive Protein Manipulation, n.d.)

The examples in Figure 8 of a protein model displayed within a CAVE at the UC Davis W.M. Keck Center for Active Visualization in the Earth Science demonstrate how PIAEs allow not only for magnifying objects on a large scale, but also for letting the user 'go inside' those magnified objects.

2.2.4 FLEX

Figure 9 - Mechdyne FLEX (Display Systems: 3D & Advanced, 2008)

With FLEX, Mechdyne took the idea of the CAVE and made it configurable into a planar three-screen display. In less than five minutes, a single person can reconfigure FLEX into the physically immersive environment. (*Display Systems: 3D & Advanced*, 2008)

2.2.5 Mobile FLEX

Figure 10 - Mechdyne Mobile FLEX (Display Systems: 3D & Advanced, 2008)

Like the original FLEX, the Mobile FLEX can be configured in either a planar three-screen display or as a four-screen PIAE. The Mobile FLEX can be transported in a truck and can be set up and configured in four hours (*Display Systems: 3D & Advanced*, 2008).

Interactivity in Mechdyne's models is afforded through Pinch gloves, which through sensors detect contact between two or more fingers, and generic peripheral devices.

Figure 11 - Mechdyne interaction devices (Display Systems: 3D & Advanced, 2008)

2.2.6 EON Icube

Figure 12 - EON Icube (EON Reality, 2008)

The EON Icube, produced by EON Reality, is a 3-, 4-, or 6-wall PIAE constructed of acryl screens, which afford high brightness rear projections (see Figure 13). The screens are attached to an aluminum enclosure structure. The Icube's projectors provide a 1400x1050 pixel resolution, 3,000 ANSI Lumens, and seamless projection. Additionally, the Icube features 3D motion tracking and a 4 channel 500W surround sound system. Interactivity with the environment is achieved through a data glove or a wireless wand. In order to create content for the Icube, EON has developed Icube Software which is touted as being easy to use for non-programmers. It allows for importing generic CAD and 3D formats, collaboration from multiple users, and sensory interaction.

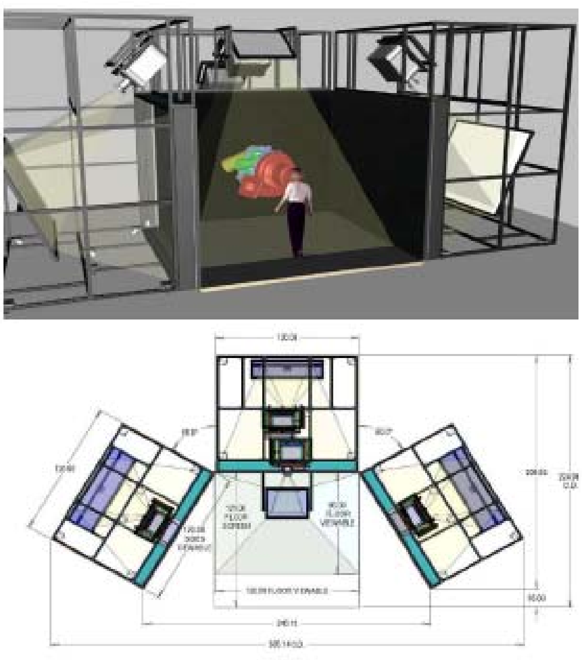

Figure 13 - EON Icube configuration (EON Reality, 2008)

2.2.7 SEER

Figure 14 - Barco Simulation SEER (SEER, 2005)

The SEER, also by Barco Simulation, includes a lot of technology in a small area. The spherical shape allows for up to 270 degrees FOV and the shape maintains constant distance between the wall and the user's eyes, preventing eye adjustments for geometric changes in the projection surface. Up to eight projectors are kept properly aligned by a laser diode array tool (LDAT). The compact physical nature of the SEER results in a small footprint and a low height. Multiple SEERs can be linked together for networked training, such as pilots flying lead and wingmen. (*SEER*, 2005)

3. Perceived and Documented Benefits

Since the initial reaction to a PIAE is often something along the lines of, "Wow! That's cool," it is easy to believe that its use is a great idea. However, the real benefits of using such an environment are not always obvious. There are numerous supposed, perceived, and documented benefits of PIAE usage for educational experiences and the research validating these benefits varies widely.

3.1 Novelty and Holding Students' Attention

It is easy to be seduced with technological wonderment by PIAEs, and this phenomenon does play some sole in their educational value. Attention to a domain is a prerequisite for learning, and newer technologies tend to attract and hold students' attention better than older ones (Furness, Winn, & Yu, 1998). Such attention is important; since knowledge is not easily transferred, students must be motivated enough to form understanding in their own minds (Noel-Storr, 2004). Even if immersive environments, in and of themselves, did not yield explicit

educational benefits (e.g. higher test scores resulting from PIAE usage), their usage could be substantiated by the notion that they retain students interest' in the subject, allowing learning to occur.

Furthermore, as PIAEs typically surround the learner, they result in an omnipresent virtual world. If the learner turns his or her head, the virtual world still fills the field of view, which inhibits outside distractions (Furness, Winn, & Yu, 1998). The proverbial daydreaming while staring out the classroom window is alleviated.

3.2 Positive Attitude Toward the Domain

There is some evidence in the literature to indicate that PIAEs may have a positive impact on learners' attitude toward the domain being presented. An inquisitive attitude is most effectively developed in practical environments, and PIAEs are often as practical or even more so (as in the case of dangerous or micro-scale conditions) than real environments (Noel-Storr, 2004).

It has long been held that "achievement of favorable attitudes is...an important aim of science education" (Fraser, 1978, p. 514). Students' attitude toward science correlates with achievement, influences their selection of science courses, and affects their likelihood of choosing a career in a science-related field (Smist, Archambault, & Owen, 1994).

The Test of Science-Related Attitudes, or TOSRA, was developed by Fraser in 1978 and has since been judged and validated as an excellent measure of science-related attitudes due to its empirical validation (TOSRA; Fraser; Smist et al.). The TOSRA is broken down into seven sub-scales, which allows for the determination of areas where students' attitudes are less positive. These areas can then be targeted for intervention (Smist et al.). The sub-scales include:

1) social implications of science (i.e. "attitude toward the social benefits and problems which accompany scientific progress" (Fraser, p. 509)); 2) normality of scientists (i.e. "an appreciation that scientists are normal people rather than the eccentrics often depicted in the mass media" (Fraser, p. 509)); 3) attitude to inquiry; 4) adoption of scientific attitudes (i.e. "open-mindedness, willingness to revise opinions" (Fraser, p. 511)); 5) enjoyment of science lessons; 6) leisure interest in science; and 7) career interest in science (Fraser; Smist et al.). The entire test is designed with a single set of instructions and a single response format, i.e. a 5-point Likert scale, and can be used to track longitudinal changes in learners' attitudes (Fraser).

3.3 Contextual Learning

Providing a context in which learning can take place "reflects the situated nature of knowledge" - learners are not reliant on accounts of third parties (including text/literature) since they experience the environment themselves (Lombardi & McCahill, 2004, p. 2; Jackson & Winn, 1999). Context makes learning easy, effective, and useful (Furness, Winn, & Yu, 1998). VEs, particularly PIAEs, can provide that context since they provide "firsthand interaction with knowledge domain representations," which allows for retaining and generalizing knowledge better (Jackson & Winn, p. 2). That interaction with the environment can ensure mental and/or physical activity and such is required for complete engagement (Noel-Storr, 2004; Furness, Winn, & Yu, 1998). Such contextual learning - which facilitates constructivism - would not be possible in the traditional classroom (Youngblut, 1998). Furthermore, PIAEs afford the ability to use authentic tools in the environment (Furness, Winn, & Yu, 1998).

3.4 Experience Physically Inaccessible Environments

One of the most useful aspects of virtual environments is their ability to transport users to places that would otherwise be physically inaccessible, due to any myriad constraints, including time, distance, and safety (Jackson & Winn, 1999; Furness, Winn, & Yu, 1998; Youngblut, 1998). The content of PIAEs is scalable - it can be the size of a solar system or of a quark. They can offer multiple points of view and typically safer than real-world scenarios. Further, PIAEs allow users to manipulate characteristics that could not be altered in reality, such as physical laws like gravity, so they can observe the effects on the environment (Furness, Winn, & Yu; Youngblut).

3.5 Constructivism and Experiential Learning

Under the constructivist school of thought, "learning is facilitated through the construction of concepts built from the intuitions that arise out of their direct experience of the environment" (Jackson & Winn, 1999, p. 3). This is important, since education that occurs in an inquiry based manner is the most effective for science learning (Noel-Storr, 2004). Learners are forced to move from being passive recipients of information to active participants in the knowledge creation process (Lombardi & McCahill, 2004).

PIAEs support such experiences because teachers tend to be less lecturers and centers of attention and more facilitators that support their students' discovery of ideas (Lombardi & McCahill, 2004; Youngblut, 1998). "Intrinsic motivation is increased if the learner has 'ownership' of experience and control over or personal involvement in the experience" (Furness, Winn, & Yu, 1998, part 2.II, Experiential Learning section). Students are free to explore and to make discoveries on their own and have the opportunity for more serendipitous educational

experiences (Furness, Winn, & Yu, 1998; Lombardi & McCahill, 2004).

PIAEs allow students to interact both with the surrounding environment as well as with each other. It is this interactivity, rather than simply being in an immersive environment, that is the determining factor in educational benefits, as it leads to constructivist learning, as explained earlier (Byrne, 1996).

3.6 Student Interaction

Experiential learning facilitates peer collaboration, which forces learners to clearly articulate their ideas in order to communicate. Further, in order to resolve any conflicts that might arise from the collaboration, learners must justify their positions, which requires reflection and deepening understanding (Jackson & Winn, 1999; Furness, Winn, & Yu, 1998; Lantz, 1996).

3.7 Multimodal Interaction

It should not be assumed that the extent of the educational benefits of PIAE experiences will be the same for all learners, as there are many different learning styles (Furness, Winn, & Yu, 1998). However, since many different modes of learning are feasible in PIAEs, consequently a larger percentage of learners should find benefit from them. For example, text-based MUDs and MOOs do not favor many learning styles, but PIAEs can incorporate imagery, sound, interaction, peer collaboration, expository teaching, experiential learning, and more. Further, the interaction in PIAEs can be intuitive, e.g. not a keyboard interface (Lombardi & McCahill, 2004). PIAEs are advantageous when learning complex subjects, since learners do not have to master a symbol system first - but can interact directly with the environment - and skill in symbol systems will vary among learners (Furness, Winn, & Yu; Lombardi & McCahill).

3.8 Concrete Content and Concrete Representations of Abstract Concepts

Human beings process concrete symbols better than abstract ones (Byrne, 1996). The virtual reality within PIAEs allows learners to focus on mastering the content being presented, not on the abstract symbol system that would otherwise have to be employed to convey the lesson (Jackson & Winn, 1999). Further, abstract information can be communicated via concrete forms and visual metaphors (Bryne; Jackson & Winn). Using fewer abstract symbol systems leads to "more direct and more robust knowledge construction" (Furness, Winn, & Yu, 1998, part 2.II, Symbol Systems section).

Another benefit of using visual representation of abstract concepts is that additional modalities of presenting information will play to different learners' strengths. Text-based environments, such as MUDs and MOOs, do not favor many different learning styles, and are less intuitive - i.e. harder to manipulate and navigate for many people - than PIAEs (Lombardi & McCahill, 2004). Further, skill in symbol systems varies among people, so the common denominator of concrete representations can be beneficial (Furness, Winn, & Yu, 1998).

3.9 Spatial Abilities

There are several different spatial ability factors, including spatial visualization and spatial orientation. The former is concerned with visualizing changes in the external frame of reference, such as imagining an object being rotated. The latter concerns the egocentric frame of reference, or the ability of the observer to imagine different perspectives of the same location (Hegarty & Waller, 2004).

There is some indication in the literature that exposure to and interaction with PIAEs may

have an effect on one's spatial abilities (as well as other VE abilities that have not yet been identified; Furness, Winn, & Yu, 1998). In one study, students in a VE developed better understanding of architectural spaces than those only using traditional CAD-based tools. In another, students in an immersive condition were able to better explain the three dimensional nature of electric fields than their non-immersed counterparts (Youngblut, 1998).

3.10 Repetition

PIAEs allow students to repeat exercises, with or without variation, and to visit environments multiple times. Learners can test hypotheses and can use all needed time to master concepts, principles, and skills (Furness, Winn, & Yu, 1998).

3.11 Physically Immersive Environment

The design of PIAEs has benefits over other virtual 2D environments. It enables a wide field of view, which allows for entire large models to be shown at once and also fills viewers' FOV. Humans have an FOV of approximately 200 degrees horizontally by 150 degrees, or about 250 degrees diagonally (although the actual FOV is approximately elliptical, not rectangular), but typical HMDs only have a diagonal FOV of 30 to 70 degrees (Lantz, 1996; Lantz, 1997; Low, Welch, Lastra, & Fuchs, 2001). This large display surface does not depreciate the resolution, which can remain very high. Typically there is no cumbersome headgear for users to wear, so there is low user fatigue. Stereoscopy is possible and one's sense of presence, especially in hemispheric domes, is more pronounced than in 2D environments. The viewpoint is approximately the same for all users (including any instructor) and users can have angular viewing without head rotation and associated response time

considerations (which is not possible with HMDs; Lantz, 1996). And, as aforesaid, because the environment is omnipresent, the turning of one's head does not lead to distractions (Furness, Winn, & Yu, 1998).

4. Project Design

4.1 Rationale

Throughout the last decade the number and complexity of physically immersive artificial environments has increased.

However, the benefits of these environments in an educational setting have not been extensively explored. It is easy to assume that in an immersive environment, students learn more – and enjoy that learning more – than in a traditional classroom setting. The "wow" factor of immersive environments is high. Many people are attracted to this new setting because of its novelty without considering whether it has intrinsic educational value. Further, it seems intuitively obvious that a student would glean a better understanding of functions and anatomy of, for example, the human brain by being physically surrounded by the brain and being able to see its structures greatly magnified and in proper spatial relation to each other. Such reasoning could lead to the conclusion that experiences in a PIAE would also lead to increases in spatial abilities, since learners are viewing and interacting with content that is surrounding and perceptually three dimensional. However, without empirical evidence, any benefits, and any putative causes of those benefits, remain conjectural.

At RIT, researchers have been experimenting with PIAEs that are immersive to various extents. In an interactive workspace known as the CollaboRITorium, students, faculty, and staff constructed an apparatus of four screens with rear projection that could be configured into a V or

into a cube. When the screens were in the V configuration, learners were in a semi-immersive environment (see Figure 15). Forward-facing flight simulations and wide screen presentations worked well in this setup. When the screens were folded into a cube, learners were completely immersed in an artificial environment (see Figure 16). This fully immersive setup was used for scenarios such as exploring brain models, viewing planetary and solar system models, observing graphically-represented network traffic, and steering a fish through an underwater environment.

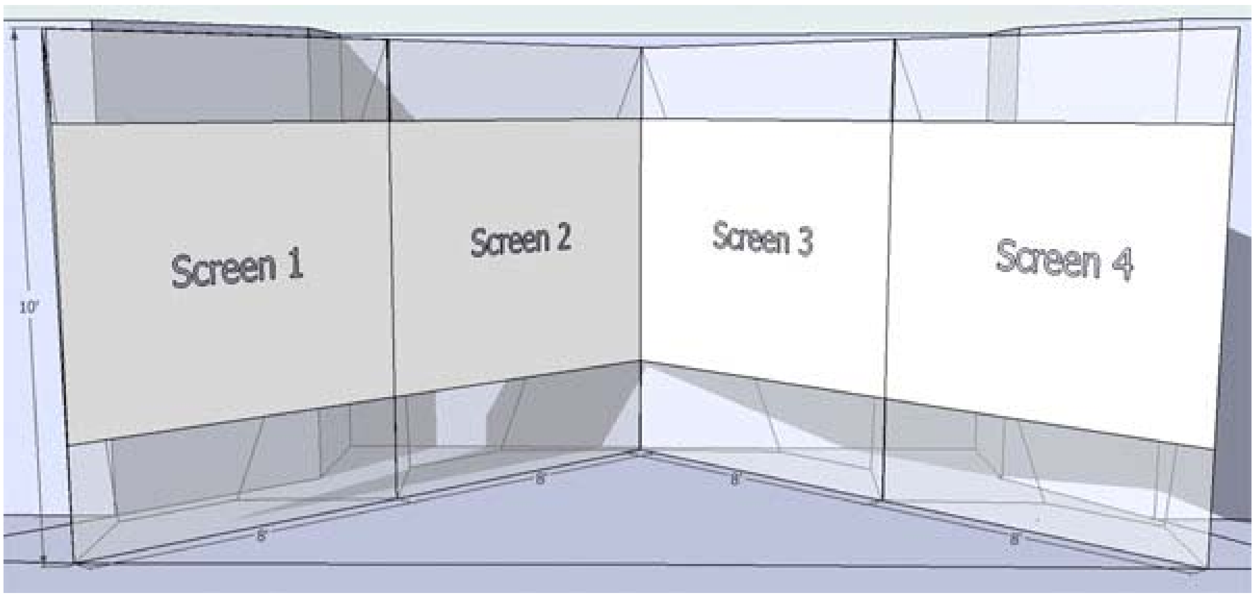

Figure 15 - CollaboRITorium screens in V configuration

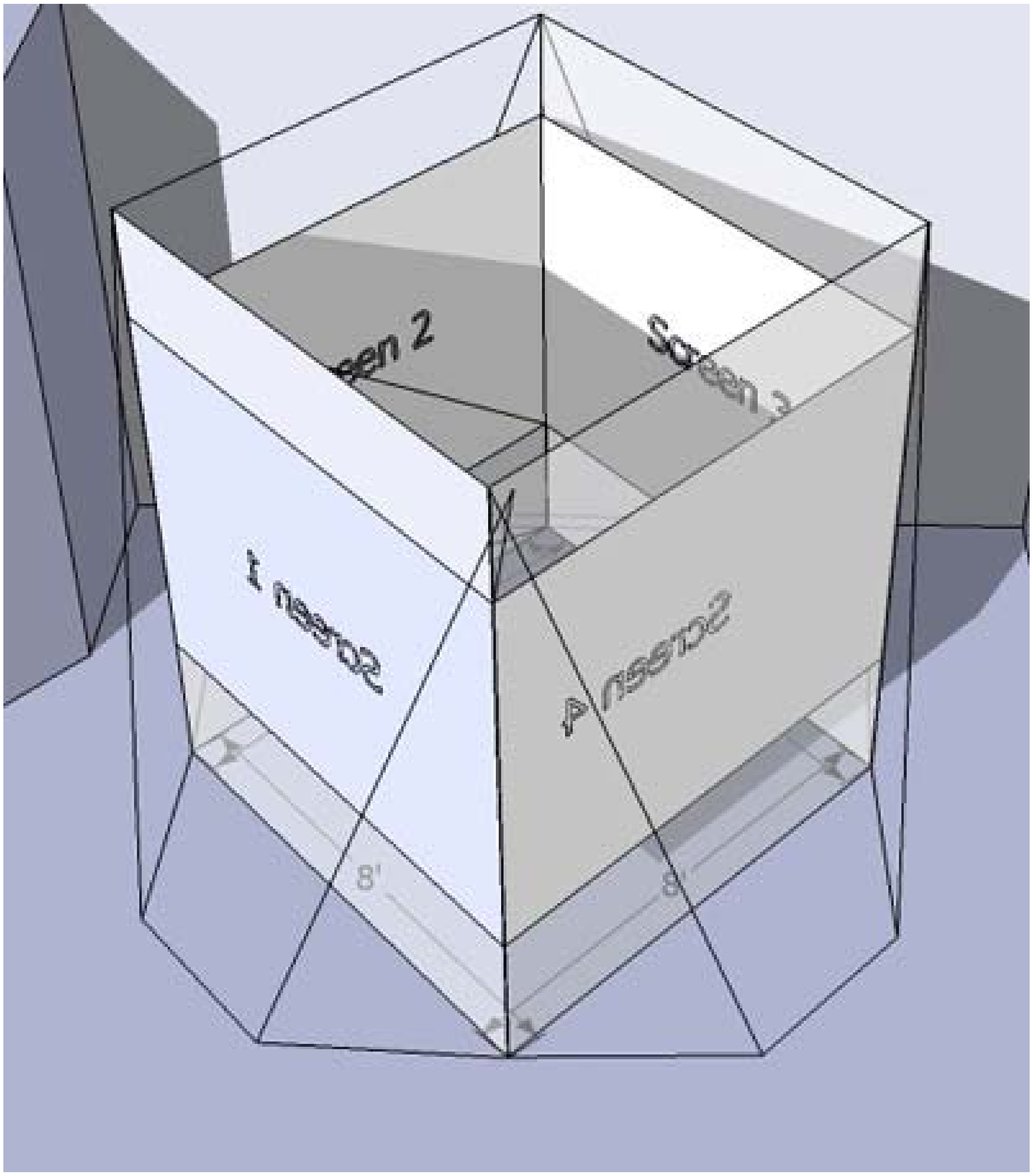

Figure 16 - CollaboRITorium screens in cube formation to achieve fully immersive environment

4.2 Subject Population

All students who registered for the two Frontiers of Science courses (I and II) at the Rochester Institute of Technology during the spring quarter of the 2007-2008 school year were asked to participate in the research project. The nine students who enrolled in the courses agreed to participate and signed an informed consent document approved by the RIT Institutional

Review Board. Participants took three tests (described in Section 4.4) at the beginning of the quarter and repeated the tests at the end of the quarter after the completion of the last class.

The Frontiers of Science courses met three times each week, two hours each day, for ten weeks during the spring quarter. The Frontiers of Science I class consisted of four weeks of lectures on themes such as “Big Bang and Black Holes,” “NanoPower,” “Vision and the Mind.” and “Viruses: Friend or Foe” by experts in their respective fields. The lectures were held in the CollaboRITorium using the 4-screen, V-configuration format (discussed in Sections 4.1 and 4.3). Subsequent to the weeks of lectures were six weeks of interactive learning projects. Some of the projects consisted of physical laboratory procedures. Much of the project work consisted of creating content for the immersive environment in the cube configuration. In order to create the immersive content, the students first had to become expert in the domain in which they were working. They then had to create some instructive content for the immersive environment that would educate learners about the domain and utilize the features of the immersive environment.

The Frontiers of Science II class built on the themes of Frontiers I. For the entire ten-week quarter, the students worked on projects to create immersive content that would allow others to learn, explore, and experiment.

4.3 Environment

The Frontiers of Science courses were held in the CollaboRITorium at RIT, a classroom with a 4-screen apparatus in the front of the room that could be configured into a V (see Figure 15) or into a cube (see Figure 16). The screens were constructed of an elastic material stretched over an aluminum piping framework. Each screen was constructed in stand-alone fashion so that it could be moved independently of the others. A short throw projector was placed behind each

screen and mounted on the framework, so that as the screens pivoted, the projectors also moved. The projectors were connected to a Windows XP computer (dubbed the 'immersibox') via two Matrox TripleHead2Go modules. Since the triple heads resulted in the capacity for six screens, the first and last outputs were not used. To achieve the fully immersive environment from the V configuration, Screen 1 rotated 90 degrees to be parallel with Screen 3, and Screen 4 rotated to be parallel with Screen 2 (see Figure 16).

To interact with the environment, students could use a wireless keyboard and Gyration's Air Mouse GO or a Nintendo Wii that communicated via BlueTooth with the immersibox.

4.4 Procedure

As mentioned above, each student was administered three tests at the beginning (the pre-test) and at the end (the post-test) of the ten-week quarter:

4.4.1 Vandenberg Mental Rotations Test (Hegarty & Waller, 2004; Peters et al., 1995; Vandenberg & Kuse, 1978)

One form of spatial ability is to imagine changes in one's mind in the external frame of reference, i.e. visualizing the manipulation of an object. To test this ability, we employed the Vandenberg Mental Rotations Test. In this test, the student compared an object composed of several blocks with four other similar objects, two of which are identical to the first except that they are rotated. The student was tasked with identifying these two identical but rotated objects. There were twenty different sets of objects for the student to identify.

In the example in Figure 19, the student would have to determine which of objects 1-4 were identical to the object on the left. The correct answer is 1 and 3 since those two show the same object as the one on the left, only rotated. Objects 2 and 4 are different arrangements of cubes and thus not identical to the one on the left.

The student received two points for each set of objects if the correct two were identified. If only one object was identified and it was a match to the initial object, the student received one point for the set. If the student identified one object correctly, but identified another incorrectly, the student received no points for the set. In total, the student could earn 40 points.

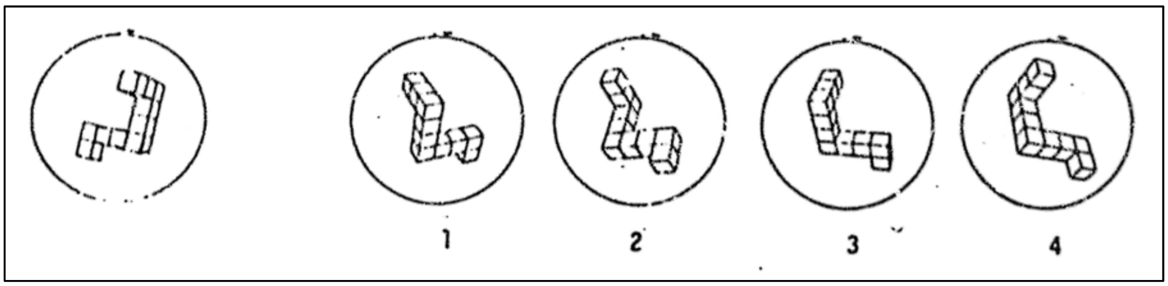

Figure 17 - Vandenberg Mental Rotations Test (Vandenberg & Kuse, 1978)

4.4.2 Hegarty's Object Perspective Test (Hegarty & Waller, 2004; Hegarty, Kozhevnikov, & Waller, 2004)

Another factor of spatial ability is perspective-taking skill, which concerns the egocentric frame of reference. It involves the ability of the student to imagine different perspectives of the same location.

To test spatial orientation abilities, we used Hegarty's Object Perspective Test. The student was presented a drawing with seven different objects and told to envision him- or herself standing at one object and facing another. The student was then to

envision pointing at another object. Below the drawing, the student was asked to draw an arrow representing pointing at the new object (see Figure 20). There were twelve different exercises in this test.

To score this test, a protractor was used to measure the angle at which the arrow was drawn. The average of the absolute value of the difference between the student's answer and the correct answer for each exercise was taken to reach a composite score for the test. Scores closers to zero indicated greater spatial orientation ability.

4.4.3 Fraser's Test of Science Related Attitudes (TOSRA; Fraser, 1978; Smist, 1994)

Fraser developed a method in 1978 to objectively measure attitudes toward science. It is composed of a series of 50 questions that illicit the student's attitudes toward seven sub-scales.

To attain anecdotal evidence that might offer more insight into the attitude changes of the students since the subject pool size was so small and in order to reduce the workload of students in this project since they were already completing the two previously described tests, a subset of Fraser's questions was used. Students were asked the following ten questions and allowed to respond with as much description as they chose.

Attitude toward Science/Career & Leisure sub-scale

a) Would you like to be a scientist or work with scientists when you graduate?
b) Would you enjoy visiting a science museum?
c) Do you ever talk with friends about new scientific inventions [or subjects covered in the class] outside of class?

Preference for Experimentation sub-scale

d) Do you think you understand answers better if you find the answers by doing experiments or if a professor tells you the answers?
e) Do you like running experiments that you have devised?

Social Importance of Science sub-scale

f) Do you think the government should spend less or more money on scientific research?

g) How is science helping to make the world a better place?

Attitude Toward Science Classes sub-scale

h) Do you like science classes?

Openness to New Ideas sub-scale

i) Do you like reading about things that disagree with your previous ideas?

j) Do you like learning about new scientific endeavors?

The results of the pre-test and the post-test were compared for each student to determine if there were substantial changes in opinion to any of the questions.

The students were charged with creating interactive content for the immersive environment. They were allowed to work either individually or in teams and could use whatever technologies and software that they desired. The majority of the students chose to create applications in Adobe Flash or Microsoft PowerPoint.

By the end of the quarter, the students had created the interactive, immersive content. For example, one student designed an application that immersed the viewer in a carbon nanotube with a given chirality. The user was able to adjust the chirality and subsequently witness the change to the structure of the carbon nanotube surrounding him or her.

4.5 Hypotheses

Three hypotheses embody the primary goals of this project:

(H1) Students who participate for one quarter in a Frontiers of Science course by creating and utilizing content for the physically immersive artificial environment (PIAE) will have improved spatial abilities in the external frame of reference. This hypothesis would be supported if the mean post-test score of the Vandenberg Mental Rotations Test significantly increases over the mean pre-test score.

(H2) Students who participate as described in (H1) will have improved spatial abilities in the egocentric frame of reference. This hypothesis would be supported if the mean post-test score of Hegarty's Object Perspective Test significantly decreases from the mean pre-test score.

(H3) Students who participate as described in (H1) will have more positive science-related attitudes. This will be assayed by the abridged version of Fraser's Test of Science Related Attitudes.

4.6 Results

To determine whether the results of the Vandenberg Mental Rotations Test and Hegarty's Object Perspective Test were statistically significant, the Anderson-Darling test of normality of the difference between the pre- and post-test scores was used. For the Vandenberg test, a perfect score is 40, so the difference between the pre- and post-test scores is calculated by subtracting the pre-test score from the post-test score. For Hegarty's test, a perfect score is 0, so the difference is instead calculated by subtracting the post-test score from the pre-test. In both instances, when the Anderson-Darling test of normality is applied to the differences, there is insufficient evidence to claim that the differences are not normally distributed, which indicates that the normal paired t-test may be applied (P=.882 for the Vandenberg test and P=.227 for Hegarty's test).

4.6.1 Vandenberg Mental Rotations Test

Figure 19 plots the students' pre-test scores on the x-axis versus the difference of their post-test minus pre-test scores. As a score of 40 on the Vandenberg Mental Rotations Test would be a perfect score, points closer to the right of the plot indicate better scores on the pre-test. Since the y-axis measures the difference between pre- and post-test scores, points low on the y-axis show minimal improvement between pre-and post-tests, while points high on the y-axis show more improvement.

Of the eight students with pre-and post-test scores for the Vandenberg Test (one student did not complete the pre-test), seven had improved scores for the post-test. A t-test shows that there is a mean of 4 (which is the average amount that students improved), a standard deviation

of 3.63, and P=.008, so there is evidence that the mean score increased, which indicates an improvement in spatial ability in the external frame of reference.

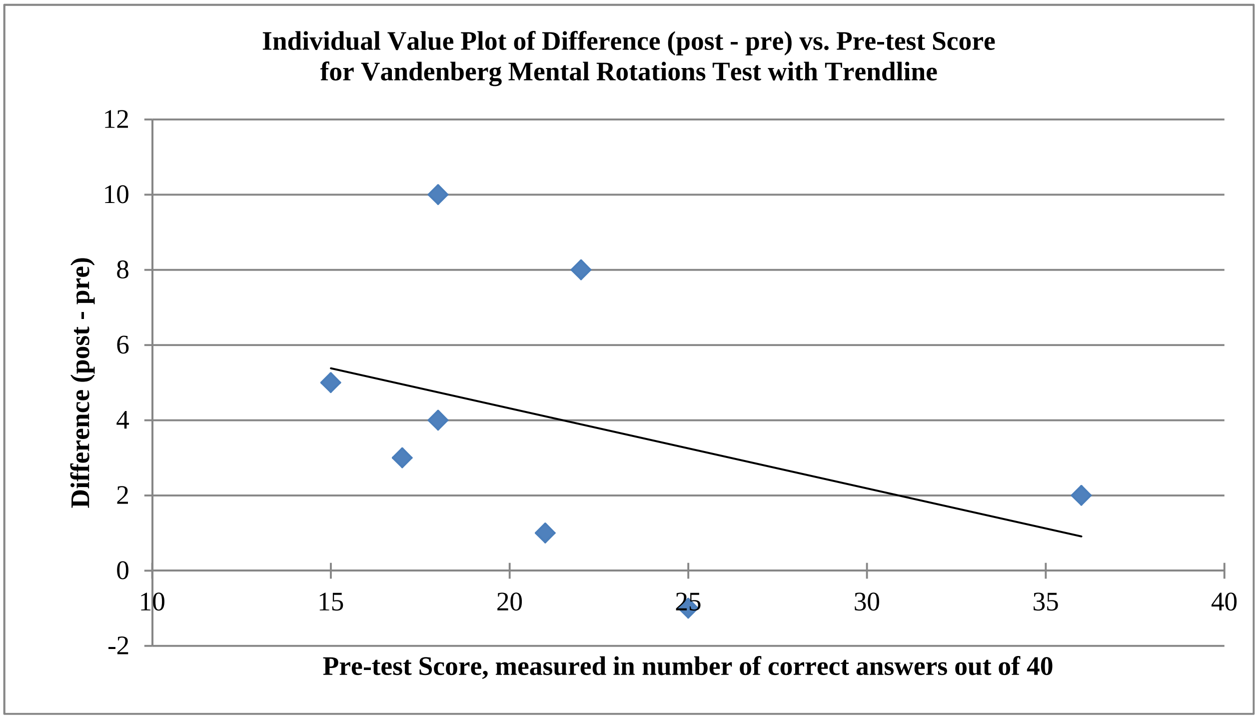

Figure 19 - Individual Value Plot of Difference (post - pre) vs. Pre-test Scorefor Vandenberg Mental Rotations Test with Trendline

The descending trendline in Figure 19 indicates that students who had lower scores on the pre-test tended to show greater improvement than students who had higher scores on the pre-test. As there is less room for improvement with higher scores, it stands to reason that students with higher scores on the pre-test would show less improvement than the students who scored lower. Therefore, the pre-test score should be considered when looking at the magnitude of the improvement. Presumably, if all of the students had scored more poorly on the pre-test, the magnitude of the average improvement in scores between pre- and post-tests would be greater.

4.6.2 Hegarty's Object Perspective Test

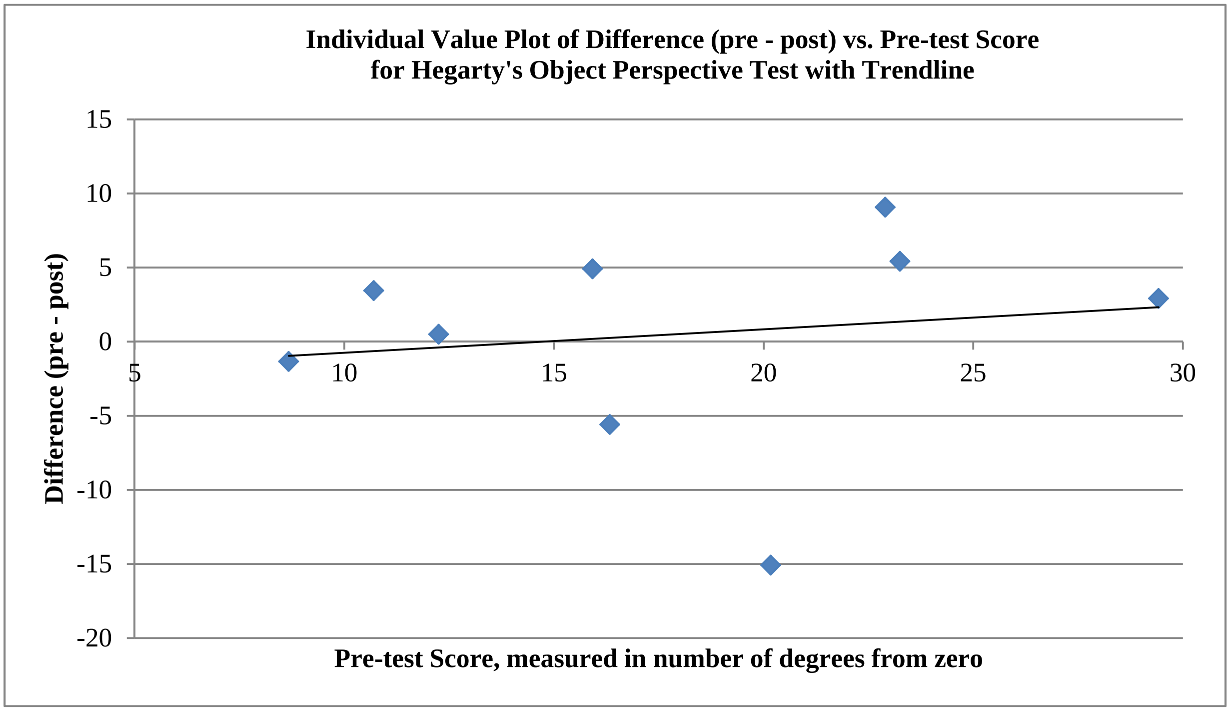

Figure 20 - Individual Value Plot of Difference (pre - post) vs. Pre-test Score for Hegarty's Object Perspective Test with Trendline

Figure 20 shows the results of Hegarty's Object Perspective Test pre-test scores plotted on the x-axis versus the difference between the pre- and post-test scores plotted on the y-axis. Note that unlike the plot for the Vandenberg test, which had better scores on the right, the plot of the scores for Hegarty's test has better scores on the left since a perfect score would be zero. To get a positive number for the difference between the pre- and post-tests, which would show an improvement in the post-test, the post-test score is subtracted from the pre-test score (unlike the Vandenberg test, which calculated the difference by subtracting the pre-test score from the post-test score).

A t-test shows a mean of .48 (which represents the average improvement) and a standard deviation of 7.20, with a P value of .424, so there is insufficient evidence to claim that the mean response decreased which would have indicated an improvement in spatial ability.

As within Figure 19, the trendline in Figure 20 indicates that students who scored more poorly on the pre-test tended to improve more than students who scored better on the pre-test. However, as the slope of the trendline is less in Figure 20 than in Figure 19, the degree of the trend is less.

4.6.3 Fraser's Test of Science Related Attitudes

Nine students answered 10 questions for both the pre- and post-tests for the abridged Test of Science Related Attitudes, resulting in 90 sets of answers (a set consists of corresponding answers from the pre- and post-tests). Only five sets showed any substantial change in attitude, each of which came from a different student. The answers that showed change are included below, not because they reflect a general pattern, but because they may be of interest to the reader.

Question: Do you ever talk with friends about new scientific inventions [or topics covered in the class] outside of class?

Answer Set 1:

Pre-test: No, I do not, it's a subject my out-of-class contacts aren't interested in

Post-test: I probably would be inclined to, but I'm a commuter so I'm not as likely to run into them outside of class. But if I did I probably would. That's one of the things

I'm liking about the RIT atmosphere: if you have those types of intellectual interests, you're actually around people who care.

Question: Do you think you understand answers better if you find the answers by doing experiments or if a professor tells you the answers?

Answer Set 2:

Pre-test: I think more when a professor tells me the answers

Post-test: probably both

Question: Do you like running experiments that you have devised?

Answer Set 3:

Pre-test: I've never devised my own experiments. Not applicable

Post-test: yes

Answer Set 4:

Pre-test: yes

Post-test: no, I tend to have trouble coming up with the experiments, so I prefer to do ones that people instruct me to

Question: Do you think the government should spend less or more money on scientific research?

Answer Set 5:

Pre-test: That's a tough one. I'd say less. They should work out their other problems first.

Post-test: I'd say more money, although I don't really know how much they're spending right now. But with all of the tech out there, they're making leaps and bounds toward curing cancer and stem cell research. They should put as much money toward it as they can while it's still popular

4.7 Summary, Analysis, and Discussion

The results of the Vandenberg Mental Rotations Test support H1. They are consistent with the idea that creating interactive content for the immersive environment does have a positive effect on spatial abilities in the external frame of reference. Other possible interpretations of these results will be discussed in section 4.8.

For Hegarty's Object Perspective Test, since insufficient evidence was found to claim that the mean response has decreased, no conclusion can be drawn regarding the effect of physically immersive pedagogy on spatial abilities in the egocentric frame of reference. It seems logical that since mental rotation abilities, on average, did appear to improve after experiences in the immersive environment that spatial orientation skills would as well. However, Hegarty and Waller have noted a dissociation between mental rotation and perspective-taking skills (2004), and these results may corroborate their findings.

Only five of the 90 answer sets to Fraser's Test of Science Related Attitudes showed substantial change between the pre-test and the post-test, and one of the five actually showed a negative change in attitude (set #4). There is too little evidence to draw any meaningful conclusions from these results.

4.8 Threats to Validity

There are numerous threats to the validity of the aforesaid conclusions, due to both the nature and scope of the project, as well as the project design itself. Although the results of the Vandenberg Mental Rotations Test were found to be in support of the H1 hypothesis that creating interactive content for a PIAE does have a positive effect on spatial abilities in the external frame of reference, these results could be attributed to other causes as well. For example, familiarity with the test (having already seen it during the pre-test) may have been responsible for the average increase in the participants' scores (The literature indicates that a single repeat of the test may result in an increase in performance; Peters et al., 1995). Students self-selected by registering for the Frontiers of Science course, which could have impacted the results, and the small number of participants makes drawing significant conclusions difficult. The Hawthorne effect, in which participants behave differently if they know that they are part of an experiment, may also have had an impact on the results.

The experimental design of this study is not beyond criticism. In an ideal situation, there would have been a class serving as a control group with all of the same characteristics as the Frontiers of Science courses, except for the use of the PIAE. It would certainly be better also for both the control group and the test group classes to have many more students than in this study.

Unfortunately, the nature of the Frontiers of Science courses and the number of students enrolled did not allow for a control group to compare against this test group. Numerous factors contributed to making a control group a difficult proposition. These Frontiers of Science courses were the first classes taught in the immersive environment that were not involved in the physical

creation of the environment, and as such, students knew very little about the courses when enrolling in them, so enrollment was decidedly low. Furthermore, the goals of Frontiers of Science were mostly not content driven in the traditional sense; that is, the courses had goals such as teaching the students to "think like scientists" and to employ the scientific method, to think outside the box, and to search for answers for themselves, piquing their interest in various scientific topics, and improving their attitude toward science. There was relatively little expository teaching – students were expected to discover a significant amount on their own. In addition, the environment of the classes was unlike any others taught at RIT, employing a physically immersive artificial environment.

An ideal course to serve as a control group would have the same goals of modifying students' ways of thinking and attitudes toward the domain, would also rely heavily on discussion, interaction, and discovery learning, and would cover the same topics, but it would use more traditional technologies, such as PCs, in lieu of the immersive environment. Without such a control group, one cannot be certain that the changes in attitude and mental rotation abilities as found in this project were attributable to the PIAE.

4.9 Further Discussion

The field of psychological and educational benefits of PIAEs is broad, and there are many other interesting variables that may affect learning in an immersive environment that were not taken into consideration in this study. Such variables include: motion sickness or dizziness in the immersive environment; fatigue; gender; learning styles; learning disabilities; physical disabilities; sense of presence; quality and duration of the interaction design; content design vs.

solely content usage; subject matter; interactivity controls; size and shape of the PIAE; and projection resolution and brightness.

The extent of each of the potential benefits listed in Section 3, such as novelty, contextual and experiential learning, or interaction, could themselves positively or negatively affect the results of this project. For example, the influence of novelty in the immersive environment is not known, although it would seem likely that novelty plays some role in, at least, the development of attitudes. Further, novelty is a transitory property and as PIAEs become more commonplace, its effects will undoubtedly erode. The effect such a change will have on other benefits of the environment is also unknown.

4.10 Conclusion

This project obtained evidence in support of the H1 hypothesis that creating and utilizing immersive content in a PIAE, increases spatial abilities in the external frame of reference. However, due to the numerous confounding variables and other threats to validity, more research is necessary to attribute these changes to the immersive environment with greater certainty.

Furthermore, while outside the scope of the present study, course evaluations and other anecdotal observations from student comments indicated that the experience was motivating, stimulating, and led to self-reports of enhanced learning. A couple of students reported in course exit interviews that they believed that the use of immersive environments in visual areas – such as exploring human lungs, outer space, or carbon nanotubes – would aid in learning, while their use in courses that are typically more discussion-based – such as literature – would not be as helpful. One student emphasized that the ability of PIAEs to show systems in motion (e.g. air

flow in the respiratory system) and their affordance of student interactivity were very important. Other students found the immersive environment to be “fun” and “engaging”.

This study lays the groundwork for future research. By employing the tests used in this study on a large scale, researchers may gain further insight into the psychological and educational benefits of PIAEs. It is the conclusion of this researcher that there is significant potential psychological and educational benefit in physically immersive artificial environments that warrants further deployment and study.

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