Simulated Ecological Environments for Education: A Tripartite Model Framework of HCI Design Parameters for Situational Learning in Virtual Environments

by

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For Heather Sky Harrington and all of the children of the Earth

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Simulated Ecological Environments for Education:

A Tripartite Model Framework of HCI Design Parameters for Situational Learning

in Virtual Environments

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Abstract

While there are many studies on collaborative or guided scientific inquiry in real, virtual, and simulated environments, there are few that study the interplay between the design of the simulation and the user interface. The main research aim was to decompose the simulation and user interface into the design parameters that influence attention, curiosity, inquiry, and learning of scientific material and acts of creation for children. The research design investigates what tools support independent exploration of a space, enhance deep learning, and motivate scientific or creative inquiry. A major interest is in the role that ecological context plays in the perception of spatial information.

None of the prior work on learning in virtual environments considered a child-centric computer interaction framing, independent of pedagogy and focused on the impact of user interface parameters, such as image quality and navigational freedom. A major contribution of this research is the construction of the Virtual Trillium Trail, as it represents one square mile of biologically accurate scientific plot study data. It is a virtual environment based on statistical data visualization, not fantasy. It allowed for a highly realistic simulation and scientifically true-to-life visualization, as well as for a planned orthogonal contrast with exceptionally high internal validity in both system and statistical research design.

Of critical importance is evidence in the pilot study, that virtual reality field trips for students may be used to ***prime*** before and to ***reinforce*** after a real field trip. This research also showed ***transfer effects*** on in-situ learning activity, in both directions. Thus, supports the claim that virtual environments may augment educational practices, not replace them, to maximize the overall learning impact. The other large contribution was in the activity analysis of the real field trip, where the *Salamander Effect* is observed as an environmental event, which opened a *Teachable Moment* event for the teacher, and which was then translated into a system design feature, a *Salient Event* in the user interface. A main part of this research is the importance of such events, as ways to support intrinsic learning activity, and leverage episodic memory.

The main empirical contribution to the design of educational virtual environments was produced by the 2x2 ANOVA with the factors of *Visual Fidelity* and *Navigational Freedom*, set to high and low levels, and the evidence of different effects on *Knowledge Gained*. The tool has an impact on intrinsic learning, which is measured here by a pre-test and a post-test on facts and concepts. A two-factor analysis of variance showed a significant effect of *Visual Fidelity* on *Knowledge Gained*, $F(1,60) = 10.54$, $p = 0.0019$. *High Visual Fidelity* condition has a greater impact on *Knowledge Gained* ($M=30.95$, $SD = 14.76$), than *Low Visual Fidelity* condition ($M=19.99$, $SD = 13.39$). Photorealistic versions had a stronger impact on learning than cartoon versions. There was significant interaction between *Visual Fidelity* and *Navigational Freedom*, $F(1,60) = 4.85$, $p = 0.0315$, with the largest impact in the combined conditions of *High Visual Fidelity* and *High Navigational Freedom* on *Knowledge Gained* ($M=37.44$, $SD = 13.88$). Thus, photorealistic, free navigation virtual environments double learning, when compared to cartoon versions, *ceteris paribus*.

The next major contribution to the design of the user interface in educational virtual environments is the design and use of *Salient Events* as components to augment the virtual environment and to facilitate intrinsic inquiry into facts and concepts. A two-factor analysis of variance showed a significant effect of *Visual Fidelity* on *Salient Event* counts, $F(1,60) = 4.35$, $p = 0.00413$. *High Visual Fidelity* condition has a greater impact on *Salient Event* counts, ($M = 14.46$, $SD = 6$), than *Low Visual Fidelity* condition, ($M = 11.31$, $SD = 6.37$). Using *High Visual Fidelity* with *High Navigational Freedom* (showing a strong trend of $F(1,60) = 3.23$, $p = 0.0773$) to increase *Salient Event* counts are critical design features for educational virtual environments, especially since *Salient Events* are moderately positively correlated with *Knowledge Gained* ($r = 0.455$, $N = 64$, $p = 0.000$).

Emotional, affective, aesthetic, and subjective attitudes were investigated in the post-experience assessment of the main study on system and learning experience. *Total Attitude* is strongly positively and significantly correlated with *Awe and Wonder* ($r = 0.727$, $N = 64$, $p = 0.000$). Also important is the strong, positive, and significant correlation of *Beauty* with *Awe and Wonder* ($r = 0.506$, $N = 64$, $p = 0.000$). And the only significant subjective emotion or attitude variable, across all system conditions, correlated to *Knowledge Gained*, was *Awe and Wonder* with a slightly positive statistic: ($r = 0.273$, $N = 64$, $p = 0.000$).

Future research will investigate the complexity and causality of such interactions between the child's mental model, the virtual environment, and the user interface in the form of regression equations, partial differential equations, and Markov models.

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Introduction: Document Overview

This thesis is mostly a document that frames an old unapproachable problem in a new and approachable way for Information Science and its application to Human-Computer Interaction (HCI) and the learning sciences. Much of my time was spent finding the correct words, identifying a semantic framework, and creating an empirical framework to approach this problem. I battled with its fuzzy and shifting qualities for five years, and I think have some important findings to publish in a language that is accessible to all.

The paper is organized in the following way. The initial inspiration and framing of the problem is discussed in **Chapter 1. Background and Macro-Context**. Here, the main research problem dimensions are described and related to the conceptual framework of the Simulated Ecological Environments for Education (SEEE) Tripartite Model. This model expresses a relationship between the child, the environment, and the user interface, and the interaction of signals and information dynamics that result. The model was an important creative and conceptual construct—and a top-down design framework— for approaching this research and system development effort.

The theoretical background is covered in extensive detail in **Chapter 2. Theoretical Background and Literature Review**. This chapter filters all of the relevant work in educational research design and HCI research design of existing real and virtual geo-spatial information systems; the purpose is to identify design patterns, approaches, and methods in terms of technical systems, statistical design, and results. The product is a valuable taxonomy of SEEE HCI design parameters, and a list of best practices and heuristics, all derived from a state-of-the-art literature review.

The prior research is synthesized and organized to produce **Chapter 3. Dissertation: A Complex Ethnographic and Empirical Investigation into Simulated Ecological Environments for Education and the SEEE Theoretical Framework.** This chapter fully describes the problems and the theoretical framework surrounding those problems from both the Learning Sciences and Information Sciences research perspective. It is a general set of questions that help the reader understand the broad picture, but not the detailed statistical questions, which are presented in other chapters.

The dissertation SEEE Theoretical Framework is transferred into system and research design frameworks in **Chapter 4. Transferring the Problems and Framework into Research Aims.** Introducing and justifying the operational goals required to achieve the research goals are connected to the empirical aim of this research, which is to investigate the factors that cause an event of inquiry resulting in knowledge gained, with particular respect to the degree of visual fidelity and navigational freedom available to users within a simulated ecological environment for education.

A significant methodological feature of this study is discussed in **Chapter 5. A SEEE System as the Virtual Trillium Trail,** for the planned orthogonal statistical design demanded a system that would allow the isolation, measurement, and manipulation of the factors. The Virtual Trillium Trail is also the first model for virtual environment data simulation and a very powerful learning environment based on reality and data—not fantasy. Descriptions of the software, approach, and curriculum are also provided in this chapter.

Chapter 6. Software Designed and Engineered to Support Planned Orthogonal Contrast Research Aims describes in detail how the salience for the system was intentionally designed and engineered so as to make the statistical analysis viable and to build the required foundation for the regression models. Internal validity in both the system and the statistics was carefully ensured and built for a planned orthogonal contrast.

Independent of the software and the statistics, the application had to work well with young children, and the best method or approach is to use User-Centered Design (UCD). Thus, an iterative design approach was taken. The first prototype system of the Virtual Trillium Trail is discussed and evaluated in **Chapter 7. Pilot Study: An Ethnographic Analysis.** Activity analysis in relation to the larger user goals was conducted, the field observation of the students learning in the real world on a field trip to the real Trillium Trail being invaluable for the Main Study. Evidence of the *Teachable Moment* and the extreme personalization of the curriculum ontology were key observations of this pilot study. The *Salient Event* became a critical user interface (UI) design component in the Main Study. The data gathered on personally meaningful events contributed to an understanding of how the real field trips could be augmented by the virtual field trip – prime before and reinforce after — for statistically significant transfer effects of procedural knowledge and activity.

Chapter 8. Main Study: Detailed Empirical Investigation into the HCI Salience Design Parameters of Visual Fidelity and Navigational Freedom on Exploration, Inquiry, Emotions, and Learning, is the main empirical analysis of the thesis, which examines the effects of *Visual Fidelity* and *Navigational Freedom,* two key design parameters in this study, on intrinsically motivated learning. It does so by measuring across the salience dimensions of high and low values in *Visual Fidelity* ranging from photo-realism to cartoon-like visual representations; and in *Navigational Freedom* ranging from infinite degrees of user free choice in movement to user restricted, software designed, path movement. Furthermore, an unexpected gender effect appears to be interacting across all conditions and so a data exploration on gender was added to the evaluation. Additionally, the results of the subjective attitudinal survey are reported and interpreted.

Chapter 9. Conclusion, is a review of the major findings in both the pilot study and the main study. The results are discussed and placed in theoretical context. The results are presented in a format that can guide design trade-off decisions for the HCI researcher, designer, and practitioner. Last, an interpretation of the findings is offered for educators, teachers and anyone interested in using virtual environments for education in practice.

Chapter 10. Future Work, addresses the major future trajectories of this research.

1. Background and Macro-Context

The initial inspiration and framing of the problem is discussed. Here, the main research problem dimensions are described and related to the conceptual framework of the Simulated Ecological Environments for Education (SEEE) Tripartite Model. This model expresses a relationship between the child, the environment, and the user interface, and the interaction of signals and information dynamics that result. The model was an important creative and conceptual construct—and a top-down design framework— for approaching this research and system development.

1.1. The Seed

How does a child start to explore a new space, virtual or real? What causes scientific inquiry? What causes creation? A powerful emotional experience is intuitively regarded as a viable causal factor in acts of creation, and insight is viewed as a key cognitive event for both scientific and creative activity. Skill and knowledge level can influence perception, as well as the speed and the quality of execution. Tools and technology can augment the environment, by making it more conducive for creation, and the process, by making it more efficient or richer in meaning. Following the main question of this research, ***"Can simulated ecological environments of nature inspire independent exploration, acts of inquiry, an intrinsic desire to learn, emotional enjoyment, and acts of creation in the child?"*** To answer this question, this research demands a system where one can measure, modify, and record changes to the virtual environment and user interface, as well as assess the child's pre- and post-experience perceptions, knowledge, and motivation. The empirical aim of this research is to investigate the factors that cause an event of intrinsic inquiry resulting in knowledge gained and acts of creation.

The activity of real-world learning for children could be supported with technology in far more vivid, engaging, spontaneous, and deeply meaningful ways than is currently available. The seeds for this research were planted by casual observations my daughter made while learning about nature on a hike; they grew into an idea for a new type of human computer interaction application and simulation. This application, referred to as ***Simulated Ecological Environments for Education*** **(SEEE)**, is comprised of three top-level components: the simulation, the user interface, and the mental model of the child.

The simulation application, SEEE, is a scientific visualization of ecology data, and the child's interaction with the software reflects that of a real-world field trip activity to a wildflower reserve. Visualizations, especially abstract presentations of semantic objects such as the one found in the Knowledge Sea portal, have been used before, and can represent a point of entry into multidimensional information and ontologies. Some can stimulate horizontal hypermedia navigation for learning (Brusilovsky, 2002, 2004a, 2004b). Thus came the extension idea to make the point of entry a realistic 3D computer graphic model. This top-level simulation is highly realistic, yet represents the entry point for a network of abstract knowledge. The ontological model of the facts, concepts, values, and the curriculum is automatically expressed as part of the user interface upon inquiry. The expert knowledge of the real environment is represented by biologists' plot study and transect data, as well as geo-spatial terrain data, and represents what was found in the field guides and the Audubon Society's curriculum. That knowledge is embedded in the system as semantic attributes of the 3D objects. How can such technology augment educational and self-directed learning activities for children? Can the child experience a sense of awe and wonder, as they might in the real world? Does beauty, freedom, and truth matter in such environments? My main high-level research question is the following:

"Can simulated ecological environments of nature inspire independent exploration, acts of inquiry, an intrinsic desire to learn, emotional enjoyment, and acts of creation in the child?"

Elementary school science lessons are largely taught to children in the classroom. The idea of situated learning and education is not new, and there is room for growth (Anderson, Reder, & Simon, 1996). The science curriculum may include separate units on nature and ecology, biology, chemistry, and physics. Most material is presented in conventional ways—with books, lectures, and in-class or lab activities. On certain occasions, field trips to local places of interest, such as to a local nature reserve with an expert in the subject area, provide meaningful experiences and ways to interact with and explore information in a broader context. Surrounding the student in the context and environment with expert role-models represents the optimal practice, according to Situated Learning Theory (Lave & Wenger, 1990; McLellan, 1995).

This broader context is spatial, temporal, multi-dimensional, multi-signal, multi-modal, and multi-faceted. On site, the children can see, hear, feel, smell, and even taste items under investigation, in what is, essentially, a multi-signal, multi-modal, real-time, situational learning environment that is simulated, supported, and augmented in a virtual reality learning environment. In terms of the theory of Multiple Intelligences (Gardner, 1983) this type of multi-sensory experience is powerful, as it provides many kinds of signals varying in importance for each type of intelligence. Integrating data, information, and knowledge from the experience can leave a lasting and meaningful impression, resulting in deep conceptual change for the child.

Sometimes, a surprise is triggered by an unexpected find, which makes the experience that much more memorable: a Turkey hen on her nest, a doe and her faun bolting, a Great Blue Heron in flight, a Pileated Woodpecker hammering, a water snake swimming. Episodic memory is more accurate and more stable over longer periods. Learning new material in the field appears grouped to similar items in memory, which are organized around the same concept according to their salient feature differentials, (Kolodner, 1983).

If the community is fortunate enough to have school science programs that incorporate natural and local resources into the science curriculum, those experiences also have the potential to become personally meaningful. These events can become powerful learning activities, part of the information and ecological knowledge base for the children. A science lesson in the field can empower a child to know more about the plants, animals, and interacting dynamics found, for instance, in their local parks.

Figure 1: Real -world field trip and situated learning
The photographs above are of my daughter at the Beechwood nature camp in the summer of 2004.

These "backyards" then become rich in information, to be shared with friends and family afterward; moreover, they may provide important access points for the creation and development of *Islands of Expertise* (Crowley and Jacobs, 2002) particularly in science. Field study may also provide a long-term, correct, stable knowledge structure for scientific understanding, and for future inquiry and learning.

One such integrated science program currently exists between school districts and the Center for the Audubon Society of Western Pennsylvania, as implemented in the fourth-grade curriculum on *Natural Communities* (Beechwood Farms Nature Reserve, 2005) and executed at the Trillium Trail, a wildflower trail located in Fox Chapel, Pennsylvania. Here, the children experience nature and learn in the open classroom through a nationally recognized ecology educational program. The program's original vision was first implemented by Ruth Scott and Ruth Boyles in 1968, and directed by Beulah Frey (Stehle, 1988).

The Beechwood Farms Outdoor Discovery Hike philosophy (Beechwood Farms, 2005) is based on Teachable Moments (Bentley, 1995). The philosophy is founded on a guide-facilitated, but child-initiated, inquiry, in which the guide is flexible and adapts to the various finds along the way of the trail. Because these events do not have to be in the original scaffold curriculum, the educational experience is highly personalized and customized to the learner's existing knowledge. Simply put, if the children are excited about it, they get to learn about it. This intrinsic desire to know is part play (Papert, 1993; Resnick, 2004; and Bobick, Intille, Davis, et al., 1999), part "flow" (Csikszentmihalyi, 1991), and is critical because a key assumption of this approach is that self-motivation is also at the heart of creativity, and so free choice and free will are critical features. This real-time, individual inquiry supports the child's intrinsic desire to learn and supports independent exploration in a meaningful, emotionally enjoyable, and salient way.

1.2. Simulations Used for Training and Decision Support

Far away from the parks of Fox Chapel, PA, simulations have been used for decades to provide situational training and education. Flight simulators such as the Link Trainer have been used effectively since World War II to provide airplane pilot training. Automobile highway-safety human factors research has used, and continues to make use, of driving simulators such as those found at the National Advanced Driving Simulator. These systems are essentially high-end virtual environments used to conduct empirical human factors research. The user-driver and computer-car simulation can be tested in a variety of situations and permit the efficient gathering of reaction time and error rate data.

Today, the military (Morie, Iyer, Luigi, et al., 2005) and medical fields (Scharver, Evenhouse, Johnson, & Leigh, 2004) make use of immersive, desktop, augmented and mixed reality applications with haptic and even olfactory feedback capabilities for situation awareness training and procedural task transfer training in mission-critical environments. The entertainment sector, and especially theme parks like Disneyland, have also used stereoscopic visuals and audiosurround sound to increase the visitors' sense of presence and engagement.

The fields of architecture (Rosenbloom, 2004) and city planning have used 3D Computer-Aided Design (CAD) models to provide the user with a sense of place, design, space, and with first-person views prior to construction or change; as such, 3D CAD can be a powerful tool for visualizing the possible (Flaxman, 2004), or for comparing and contrasting different possible realities. Educators, professionals, and students involved in architecture, city planning and cultural heritage (Ruiz, Weghorst, Savage, et al., 2002) are currently making use of virtual environments for visualizations (Vote, 2001).

Data visualizations have allowed scientists to synthesize and evaluate large geographical data sets, the most interesting one being the Puget Sound Regional Synthesis Model (PRISM) at the University of Washington (Puget Sound, PRISM. 2005). In addition, the Smithsonian simulation of the Brazil Nut Tree and Forest, while not real-time interactive, is a very data-accurate reconstruction of a plot in a tropical rain forest ecosystem over time. Another example is the U.S. Department of Agriculture, Forest Service research methods for algorithmically creating forest simulations (Bechtold, Heravi, & Kinkenon, 2003).

1.3. Early Virtual Reality in Education

It is not a new idea to use virtual reality for education. Since the early 1990s, virtual reality has been investigated for use in education with children (Dede, 1995; Johnson, Moher, Ohlsson, & Gillingham, 1999; Wickens, 1992; and Winn, 1993). The most significant research to date has been produced at top research universities: MIT, the University of Illinois at Chicago's Electronic Visualization Lab (EVL), University of Washington's Human Interaction Technology Lab (HITLab), University of Nottingham, Harvard University, and Georgia Institute of Technology, just to name a few.

None of the previous studies were designed as highly realistic virtual environments with sophisticated user interfaces; nor were any of them designed with the purpose of educating young children about ecology, or as an entry point for developing interest in biology, chemistry, or physics and for going on to support them in their independent quest for deeper knowledge. This was the case, partly, because computer graphic software and hardware processing speeds were not capable of handling the complexity of this sort of processing.

There have been other applications designed with the educational goal of teaching ecology to children. Applications anchoring science instruction in multi-media learning environments has proven to be effective (Goldman, Petrosino, Sherood, et al., 1996). Some projects have focused on using multi-media user interfaces with intelligent tutors. The most well known projects are the Wetlands Ecology, Hi-Ce Model-It, *What is the Water Like in our River?*, from the University of Michigan's Center for Highly Interactive Computing in Education and the famous videodisc program, *Jasper Woodbury Problem Solving Series* by the Cognition and Technology Group at Vanderbilt. The Jasper Woodbury project used the highly effective teaching technique of problem based instruction strategy.

Another interactive development effort, conducted in the HP-Labs at the University of Bristol, U.K., is ARKive (Wildscreen, 2008). It is a large multimedia database project focused on the earth's biodiversity, with tools that allow users to "annotate" content with semantic web ontologies (Miller & Dingley, 2002). Even though multimedia allows a wide presentation and a regalia of content, it tends to inhibit the user's complete freedom of topic selection, as well as his or her ability to explore a three-dimensional space at will; thus, it is inherently limited in that the very nature of the medium, photographs, and video clips, constrains exploration to the area previously documented by the courseware designer. Since it would be impractical to document everything, the designer makes choices in the content, which inevitably limits or biases the information presented (Smith & Reiser, 1997). Multimedia applications are not real-time rendered interactive computer simulation models and, as such, lack the benefits or research opportunities that simulations can offer.

None of the systems to date have been created to provide an information rich, augmented virtual environment that is correctly modeled, photo-realistically or simulated as an ecological environment, and in a user interface that engages a child and allows for independent inquiry.

2. Literature Review and Theoretical Background

The theoretical background is covered in extensive detail. This chapter filters all of the relevant work in educational research design and HCI research design of existing real and virtual geo-spatial information systems; the purpose is to identify design patterns, approaches, and methods in terms of technical systems, statistical design, and results. The product is a valuable taxonomy of SEEE HCI design parameters, and a list of best practices and heuristics, all derived from a state-of-the-art literature review.

The challenge of providing visually and cognitively rich simulated environments that lead to exploration and learning for young children has been addressed in a variety of research projects during the past few decades (Wickens, 1992; Winn, 1993; Allison, Wills, Bowman, Wineman, & Hodges, 1997). For this study, that body of literature was filtered through a critical analysis towards the goal of discovering the essential components required for creating technology and software that can be used to inspire inquiry and creativity (Shneiderman, 2000).

Close to forty research projects were reviewed. There was variation in the hardware, software, and devices, but the main categories are: ubiquitous and collaborative learning, immersive virtual environments, classroom virtual reality, simulations and artificial life, theaters and science centers, desktop virtual reality environments, augmented and mixed reality, and mobile and in-situ presentations; lastly, I reviewed studies pertaining to interesting and creative elements just for children. For a full report of all detailed information, see Appendix I.

The ideal requirements for a Simulated Ecological Environment for Education (SEEE) were derived from an extensive literature review on similar systems. The goal was a horizontal sweep assessing functionality across disparate applications and projects that had main clusters of attractive functionality. ***The paper is orthogonal to a view that seeks convergence*** in an application domain. ***It is a horizontal User Interface (UI) analysis, not a vertical application analysis.*** The other challenge is that there is nothing like the SEEE from the past to which to compare, except for an environment that is more like Myst but based on real geospatial data and used for educational purposes. If I were building an intelligent tutor, then there would be many to focus on in the comparison. I was looking for design clues in projects that came close to the type of real-world experience in the woods. The SEEE is a composite of ideas from the older research with new technology that creates new research opportunities.

Imagine that this work started as four spreadsheets, with the first listing 40 projects in the vertical dimension and the factors per project in the horizontal dimension. The factors listed in the horizontal dimension are:

- Description of the project – hardware and software factors.
- Description of the research factors study (content and measurement—quantitative or qualitative).
- Description of the user interface – input, output, and soft components.
- Description of the soft user interface in detail – search, navigation, annotation, and augmentation.

The quantitative data is based on the 40 projects only. The list of features is more important then the frequency of the features. The taxonomy, which is actually quite large, is the result of this effort and consists of multiple overlapping ontologies in the three dimensions of the SEEE Tripartite Model: the user model, the virtual environment, and the user interface.

Design trade-off decisions should be informed decisions, based on evaluations of past designs. We are interested in extracting critical design parameters from successful projects that relate to implementing virtual environments for education. With this goal in mind, this qualitative research reviews and evaluates recent significant projects. The projects represent vertical applications from many domains. Each was consistently evaluated in a case-study-based approach that decomposed the projects into horizontal system components.

The components of virtual environments, simulations, intelligent tutors, and the 3D user interfaces were organized into a unified taxonomy of HCI design parameters. The horizontal HCI components transcend the application domain and are orthogonal, but not independent, of the content in the system. The problem currently faced by designers of such systems for educational purposes is one of managing the complexity of design choices inherent in such an apex of HCI taxonomies, because these taxonomies are overlapping ontologies of spatial cognitive ecologies, with multiple, sometimes conflicting, design trade-offs. The challenge is to bring a simple and elegant understanding to this complexity, as well as to offer an efficient and effective model for use in practice. We ague that, despite the complexity of the original problem state, a simple yet robust model of the problem is plausible and is offered in the SEEE Tripartite Model. The resulting framing of the problem is with a high-level hidden Markov model. Future research entails fitting empirical data to the tripartite model, as it is expected to be an elegant and robust model for user-interface design of spatial cognition or situated learning systems.

2.1. Overview of Virtual Reality in Education

In the last decade, virtual reality systems have been investigated as situational learning environments for children (Dede, 1995; Johnson et al., 1999; Wickens, 1992; Winn, 1993). However, given the state of the hardware-rendering capabilities of the past, the lack of photorealistic capabilities, and the lack of artificial intelligence models, the resulting systems lacked believability; thus, they may have failed in part due to the lack of accuracy in the simulation. Additionally, both knowledge and tools in developing the user-interface components required to augment and annotate such three-dimensional spaces did not exist. There were, however, many advances in multi-media systems that used designer-selected photographs, schematic illustrations, and video to convey information in a hypermedia paradigm on the Web.

The philosophical basis for this research was gathered from studies on situational learning (Lave & Wenger 1990; McLellan, 1995), *Islands of Expertise* for informal learning (Crowley & Jacobs, 2002), and the *Theory of Multiple Intelligences* (Gardner, 1983). In the case of teaching ecology to children, there are landmark studies, specifically in multi-media (Goldman et al., 1996). Wetlands Ecology, Hi-Ce Model-It, “What is the Water Like in our River?”, from the University of Michigan’s Center for Highly Interactive Classrooms, Curricula, and Computing in Education, and the Jasper Woodbury Problem Solving Series by the Cognition and Technology Group at Vanderbilt, used the highly effective teaching technique of *problem-based instruction*. However, *problem-based instruction* is not *intrinsically driven independent exploration*. The way a designer frames the problem will influence the users’ activities, albeit subtly.

2.2. Literature Review

The projects selection criterions were based on technically novel solutions and the empirical quality of learning outcome studies. We were interested in evaluating projects that shared situational learning pedagogy, supported independent inquiry and explorations, designed events for emotional engagement, and reflected technical superiority in visual fidelity as well as novel uses of 3D user interfaces. The content areas of science, ecology, and art reflect our research interests. Ecology is an ideal content area for investigating the unique effects of a spatial-temporal user interface on changes to cognitive models in situ.

The challenge of providing visually and cognitively rich simulated environments for exploration and learning has been attempted in a variety of research projects during the past few decades (Wickens, 1992; Winn, 1993; Allison et al., 1997). The literature reviewed consisted of projects from as early as 1994, such as Project ScienceSpace, (Dede, Salzman, & Loftin, 1996) to as recently as The MUVEs in 2005 (Dede, Ketelhut, Nelson, & Bowman, 2005). Most of the children in these projects were young, with the low end of the age range at five years old in The Field (Johnson et al., 1999) and seven years old in The Virtual Reality Gorilla Exhibit (Allison et al., 1997); and with the high end of the age range including high school students in MaxwellWorld (Dede, Salzman, Loftin, & Sprague, 1999) and college-aged freshmen in the Virtual Big Beef Creek (Campbell, Collins, Hadaway, Hedley, & Stoermer, 2002). Even when projects were not empirically tested, but deployed in public areas with the general population, there was an abundance of anecdotal reports and ethnographic data of the experience from which to learn.

From the perspective of usability methods and educational impact results, quantitative data was gathered in eight out of thirty-six projects: NewtonWorld, MaxwellWorld, Global Change World, The Round Earth Project, MUVEs 2003 and 2005, Virtual Reality in Biology Teaching, and The Virtual Field Station. Out of those, six showed significant and positive impacts on learning: MaxwellWorld, The Round Earth Project, MUVEs 2005, the Virtual Reality in Biology Teaching, and The Virtual Field Station. Three more showed no difference at all, but all projects reported to have a high level of engagement, enjoyment, and attention. Most just simply did not collect, analyze or publish data related to the learning experience, as the work focused on the technical proof-of-concept. Still, it is important to pursue the question: Why did learning occur? Can the design features be isolated and extracted for heuristic design guidelines in future work? The user-interface components were reviewed in this case study with an expert usability inspection evaluation approach.

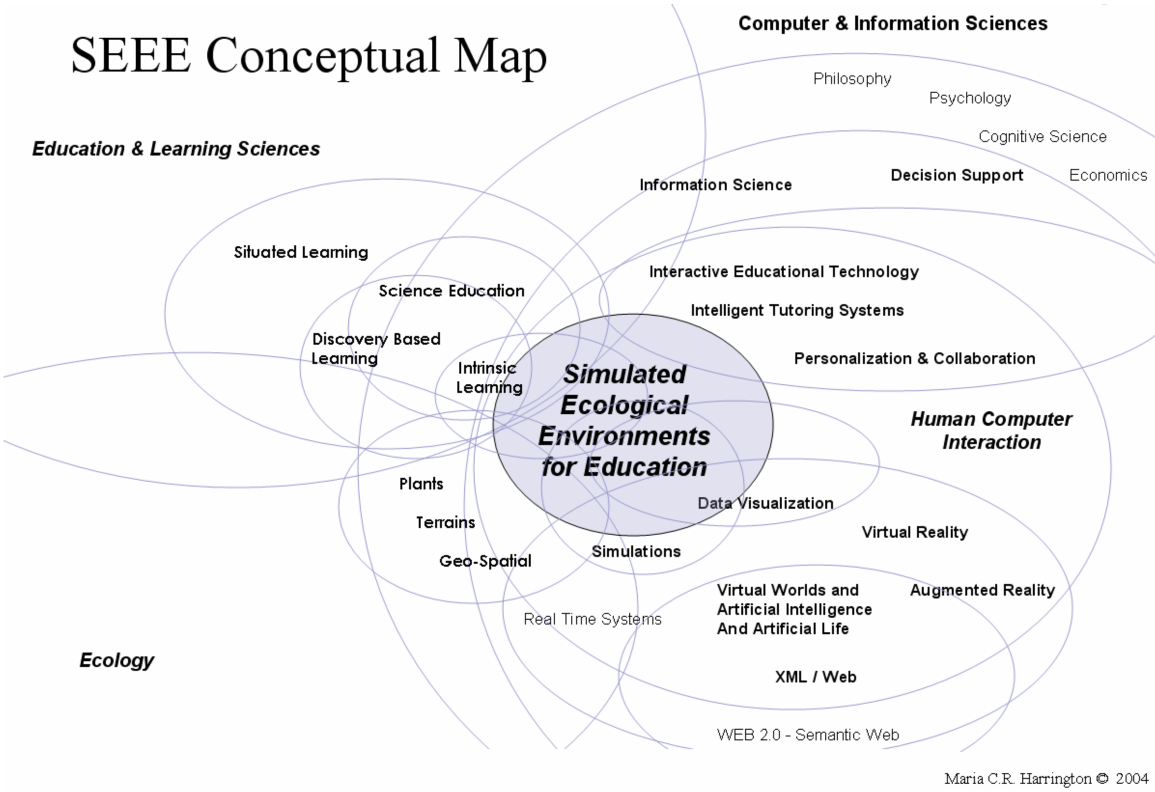


Figure 2: Conceptual map for literature review

2.3. A Sample of Projects Reviewed

2.3.1 MIT KidsRoom

The KidsRoom was created as a perceptually-based interactive and immersive story environment at the MIT Media Lab (Bobick et al., 1999). The story provided context for children to understand roles and thus to understand required actions. Through the story, the cause-and-effect correlations were made clear. Attention-grabbing, high-salience cues were needed when the kids were in a state of high activity. The technique of having different voices for different purposes represented a useful choice of redundancy gain, where the sound, gender, and type of tone were mapped to function.

The KidsRoom was an important project because it represents the ideal environment for children in which to experience immersive virtual reality. Natural interfaces and mixed reality, supporting a social group of kids, created an environment for successful imaginary play and interaction. The MIT KidsRoom application spans the main categories in HCI: mixed reality, interactive story and hyper-media video system, ubiquitous and collaborative systems, use of voice, kinetic feedback and tangibles.

2.3.2 Project Science Space

The pioneering research of Project Science Space, initiated in 1994, investigated both the educational value and immersive virtual-reality user-interface potential of HCI, producing one of the first published mental models of learning in VR as an activity (Salzman, Dede, & Loftin, 1996). This interdisciplinary effort produced evidence of knowledge gain. The most effective component was the interactive MaxwellWorld (Salzman et al., 1996) with visualized electromagnetic fields. A well-established HCI technique is to visualize data for increased exploration and understanding. The users were allowed to independently explore, create, test, and observe effects. Specifically, they were allowed to become an eclectic charge and to be propelled through the field. This 3D immersive simulation with a small problem space resulted in significant learning.

The Project Science Space (MaxwellWorld) spanned the categories of HCI and science education. The subcategories it intersected were: simulation of scientific phenomena, immersive virtual reality with augmentation user-interface elements and scientific visualization. The use of multiple frames of view with respect to the visualization represents a good design choice. The additional design element of allowing the user to “become” the object in order to experience the phenomena from a non-human perspective is an area of future research in HCI.

2.3.3 Georgia Tech Virtual Gorilla

The Virtual Reality Gorilla Exhibit was an immersive virtual environment created at the Georgia Institute of Technology and pilot-tested on location at the Atlanta Zoo (Allison & Hodges, 2000 and Allison et al., 1997). The primary goal of the system was to teach children about the social interactions, vocalizations, social structures, and habitat of the gorilla. As children commonly engage in imaginative play, they could take on an adolescent gorilla avatar and interact with the other virtual gorillas. Observed results reported were that younger children spent more time investigating and exploring the habitat, while older children spent more time socially engaging. Students did not use gestures or physical activity, as had been expected.

The Virtual Gorilla Exhibit spanned the categories of HCI and education. The subcategories it intersected were: simulation of geo-physical space, artificial intelligence and avatar development, 3D computer graphics, and immersive virtual reality. The additional element, of allowing the user to “become” an adolescent gorilla and to experience the social interactions of a different species from a non-human perspective, is an area of future research in HCI for the creation of empathetic experiences or “empath-centric” perspectives.

2.3.4 EVL Field Work and MyField Study

The EVL Field Work and MyField Study research efforts offer ideas about the integration of virtual environments into existing public school curricula held to national standards for science education. The educational objectives of The Field were to investigate how virtual reality could be used to simulate an experience and learn about the scientific process. The most recent version reported of The Field (Johnson, Moher, Cho, Edelson, & Russell, 2004) is a collaborative project focusing on sixth graders, and the technology is heterogeneous deployment consisting of: GeoWall, laptop, and handhelds with simulated GPS.

The EVL Field Work and MyField Study spanned the categories of HCI, science education, and science simulations. The subcategories it intersected were: geographical simulation of a field of plants, avatar and artificial intelligence embedded in bees, scientific visualization of data, scientific reasoning skills development, observational and hypothesis formation and testing skills, social collaboration systems, and interpersonal skill development, as well as the use of the range of heterogeneous devices in classrooms and schools.

2.4. The Main Technology Categories

Close to forty research projects were reviewed and organized into technology categories. All of the analyzed projects are presented in Appendix I in the form of tables. Of interest are the components required for creating technology and software that can inspire inquiry and creativity (Shneiderman, 2000). There was variation in the hardware, software, and devices. To start to compare and contrast such divergent systems, the following main categories were used to catalogue dimensions of hardware, software, and devices:

- Augmented and Mixed Reality
- Classroom Virtual Reality
- Creative Elements for Children
- Desktop Virtual Reality
- Immersive Virtual Reality
- Simulations and Artificial Life
- Theaters, Museums, and Science Centers
- Ubiquitous and Mobile Computing
- Virtual Reality of Virtual Environments

2.4.1 Augmented and Mixed Reality

Augmented Reality (AR) is defined a computer graphic application, model, rendering, or animation that are unique to generating and providing visual overlays to the perceived reality, for the purpose of augmentation and enhancement of the real visual information.

ARToolkit is an example of software that can be used to create AR applications (Billinghurst, Kato, Poupyrev, Rosenblum, & Macedonia, 2001). Reality is augmented by AR computer graphic information, and used to extend the perceptual and cognitive functioning of the user. Mixed Reality is AR but with the addition of real-world props. Some objects that are perceived are part of the real environment, and some are 3D computer graphics, models, renderings, and animations. Mixed Reality uses a combination of real-world props and virtual environments (Hughes, Moshell, Reed, Chase, & Chase, 2001).

2.4.2 Classroom Virtual Reality

Classroom virtual reality refers to implementation and installation of virtual reality equipment in a classroom for curriculum enhancement, such as was implemented in the Field (Johnson, et al., 2004) and MUVEs (Dede, et al., 2005).

2.4.3 Creative Elements for Children

Environments designed for play and joy, such as was implemented in MIT KidsRoom (Bobick et al., 1999), were of high interest. Emotional engagement is a key element, motivator, and can be found in technology enabling spontaneous game development or creation, such as in the Tent (Waterworth and Waterworth, 2001). Objects of creation or imaginative play are important; many examples were found in science centers or children’s museums (Corbit, 2000). These technologies are not competitive games, but are constructed to facilitate creation and imagination.

2.4.4 Desktop Virtual Reality

Desktop Virtual Environments (Virtual Reality) as were seen in the MUVEs research (Dede, et al., 2005), and the Taiga virtual world research, (Barab, Zuiker, Warren, Hickey, Ingram-Goble, Kwon, et al. 2007), are 3D computer models, renderings, or animation applications and viewed on a typical PC, or the Desktop. They require a mouse, keyboard, joystick, or game controller for control, common school equipment. They also represent a low cost entry point for integration into at home use, as was recently deployed by WolfQuest.com, and SecondLife.com.

2.4.5 Immersive Virtual Reality

Immersive Virtual Reality perceptually and physically surrounds the user by the application's output device. Often, a head-mounted display (HMD) is used to replace reality with the 3D computer graphic models, renderings, and animations; alternatively, a CAVE (Cruz-Neira, Sandin, & DeFanti, 1993) or CaveUT (Jacobson and Lewis, 2005) is used to engulf the user's whole body within the VR environment. Many of these systems have been extended to provide more information to the user through multi-modal perceptual channels—including sound, smell, touch, and even taste. Different configurations for data input have been used, including computer vision tracking of the user, data glove for gesture input, wands, mice, and voice.

2.4.6 Simulations and Artificial Life

Simulations are computer applications constructed to model, usually, the dynamic interconnected relationships of many causal variables, but not necessarily in real time or interactively. They run different independent variables through the model in order to compute the dependent variables and the situational outcome. Artificial Life (AL) is a software application or program that computes data consistent with a computational model of some life form, society, community, or aggregate of life forms found in a society as was first seen in a virtual terrarium, (Damer, Marcelo, & Revi, 1997). Some of the computational models are static-rule-based; others are dynamic and can exhibit properties of learning. The outputs of the program should be actions and behaviors that mimic the real life counterpart, at least computationally. The AL application is independent of the user interface.

2.4.7 Theaters, Museums, and Science Centers

Theaters are designed for large numbers of people. Unlike a Cave, where one or a few people may stand, theaters can provide seating for many people to experience an immersive virtual reality.

2.4.8 Ubiquitous and Mobile Computing

Ubiquitous Computing depends on environments that are saturated with computing communications abilities (Okada, Yamada, Tarumi, & Moriya, 2003). Mobile computing allows the user to interact with a device for information management tasks in a variety of indoor or outdoor settings (Rogers, Price, Randell, Fraser, Weal, & Fitspatrick, 2005).

2.4.9 Virtual Reality or Virtual Environments

Virtual Environments (VE) refers to the software and computer technology required to create virtual reality—including real-time, interactive, 3D computer graphics, models, renderings, and animations that are supported by real-time, interactive user-interfaces, models, applications, and computer hardware. Some of these models persist, while others do not. Some are static, and others are dynamic over time. Some are for only one user; others allow entire societies to interact. VEs existed in some form in most of the projects reviewed.

2.5. The Main Research Applications Categories

Transecting the categories of technology evaluation, the projects were reviewed with respect to goals, domain content, and knowledge domain. The dimensions of knowledge domain and content consisted of the following categories:

- Science of Biology, Chemistry, and Physics
- Ecological and Oceanic Simulations
- Plants and Pollination Dynamics
- Planetary and Space Science
- Scientific Investigation Methods
- Virtual Aquariums, Science Centers, Museums, Terrariums, and Zoos
- Children’s Stories in AR and MR
- Creative Constructions in 3D and VR
- Ubiquitous Field Trips in Science and History

Education as a domain has produced results in situated learning and science education with off-the-shelf, open-source virtual reality tools such as those found in ActiveWorlds, (ActiveWorlds, 2005). Science and ecology as domains have produced simulations for scientists studying natural phenomena (Puget Sound, 2005).

2.6. Summary Descriptions Found in the SEEE Tables

It is my contention that, if we could measure the convolution of signal strengths, then we might find aggregate threshold points that trigger an act of inquiry, a sense of awe, an act of scientific inquiry or of artistic creation. An attempt was made to survey and present the significant projects, methods, results and technology used, as well as to extract design parameters. All of the projects analyzed are presented in Appendix I., Literature Review Tables. The first table, “Project Summary,” summarize the projects, the educational impacts, and details of the technology used, with specific attention to the user interface. It presents the overview of the historic projects. There are thirty-six projects catalogued. This table details the project name, lab, university or organization, researchers, dates, goals, and the standards used. The subjects are mostly younger children, although some projects were not tested but instead deployed in public areas with the general population from the venue providing feedback.

The next table, "Project Summary and Results," displays the data for the educational and usability methods and results. It is very surprising that, out of thirty-six projects, only nine constructed experiments to gather statistical data, and out of those, only six showed significant and positive effects on learning. Three more showed no difference at all, but all projects reported to have a high level of engagement, enjoyment, and attention. Most just simply did not collect, analyze, or publish data related to the learning experience, as the focus was on the technical proof of concept.

The next table, "Project Features and Functions," are the data for the user-interface components, including the features and functions found in the projects. Thus, if the technology used was defined in the research publication, it is summarized here. The factors found in these tables show the content subject mater, the model and simulation, the number of simultaneous users the application could support, and the human-computer interaction dimensions. The user interface consists of the hardware, software, input devices, and output displays.

Also cataloged are the user-interface components for the virtual environments and augmented environments. Additionally, data are listed as different modalities of signal type (e.g., visual, audio, tactile, etc.), and different techniques, such as frames of reference, scaling capability (e.g., large or small, zooming), and the search and navigation modes. The navigation in 3D space can be egocentric (from the first-person perspective of the user); where the directions are often thought of in terms of left or right. It can also be exo-centric or allocentric (as from a survey view or a map view) where directions are often thought of in terms of north, south, east, and west). There is a new navigational category, referred to as empath-centric. Empathy can be a subcategory of egocentric, but with the use of human and non-human avatars. The user takes on the capabilities and perspective of that entity, as was found in the VBBC project with the eagle (Campbell et al., 2002). Last, soft-user-interface elements, such as menus, soft tools, visualizations, and decision support techniques (e.g., visualizations of the past, present, and future scenarios), are catalogued.

The last table, "Projects Matrix," represents a super-set of all of the features, functions, and educational testing methodologies. The Simulated Ecological Environments for Education is envisioned as combination of the user interface and all of the perceptual signals of the virtual environment. This table represents a starting point for future research, where each variable can be isolated and tested. It is the starting point of design.

2.7. Findings in the Literature

The findings in the literature are both empirical and qualitative. The empirical findings are few but indicate that the learning is an outcome, if the systems are well-designed and if the empirical studies are well-crafted. The qualitative findings consisted of themes surrounding that of context, collaboration, and frames of reference. Additionally, emotional outcomes of fun and enjoyment (Alborzi, Hammer, Kruskal, Lal, Schwenn, Sumida, et al. 2000; Resnick, 2004; and Bobick et al., 1999) are evident and may represent the achievement of "flow" (Csikszentmihalyi, 1991).

2.8. Empirical Findings

Knowledge gain of close to 20% was reported in the experimental results of the MaxwellWorld project (Salzman, Dede, & Loftin, 1996), a gain of close to 50% in Virtual Environments in Biology Teaching (Mikropoulos, Katsikis, Nikolou, & Tsakalis, 2003), and a gain of close to 35% in the MUVEs (Dede et al., 2005).

In an overwhelming majority of the qualitative reports, reported attributes of virtual environments for education included enjoyment, engagement, and increased attention, the strongest of which was reported by Dede et al. (2005), as data was quantitatively gathered on the proxy variables of attendance, absenteeism, and the use of profane language in classroom virtual environments. Dede et al. (2005) reported that absentee rates decreased by 35% and the use of profane language dropped by 81%. Thus, it is reasonable to assert that, if the child enjoys the experience, then he or she will spend more time engaged in the experience of learning.

2.9. Qualitative Findings

The most common findings are patterns across the projects and research efforts. These consist of context, collaboration, and frames of reference. Context is important, as it influences all signals. Collaboration is important if the task involves exploration, as it helps to reduce inhibition and increase exploration of a space. Frames of reference help to focus attention, as does the presence of salient objects found in the frame of view.

Furthermore, there are the impacts of visualization (Dede, 1996; Dede et al., 1999, 2005; Johnson et al., 1999; and Johnson, Moher, Cho, Lin, Hass, & Kim, 2002) as well as the sensitively implemented redundancy gains (Dede, 1995; Dede et al., 1999) executed in the multi-signal possibilities of the user interface (Fallman, Backman, & Holmlund, 1999). It also is paramount for the correct mapping of cause-and-effect relationships; if they are not clear, the students will not be able to learn to use the system, the UI, the VE or the educational material (Jackson & Fagan, 2000; Jackson, Taylor, & Winn, 1998).

2.10. The HCI Features and Functions

The features and functions found in the projects were organized into the following categories: 1) data-created simulation were found in 53% of the projects; 2) artificial life was found in 44% of the projects; 3) intelligent, adaptive, or nonlinear story-line was used in 17% of the projects; and 4) ambient life found in 17% of the projects.

The number of simultaneous users the application could support was an additional category investigated with: 1) single users representing 47% of the projects; 2) dyads in 33% of the projects; and 3) collaboration in 69% of the projects. Some of the studies compared one group-type of users to another group-type.

The user interfaces surveyed consisted of hardware, software, input devices, and output displays: 1) Immersive VR with HMD represented 11% of the projects; 2) Immersive VR with Cave or Theaters represented 42% of the projects; 3) AR and MR was used in 36% of the projects; and 4) Desktop VR was used in 42% of the projects. Some of the studies compared one type of technology configuration to others or combined them for a heterogeneous environment.

Also cataloged are the user interface components at a finer grain size: 1) Input devices of a mouse and keyboard with arrow keys were employed in 44% of the projects; 2) Handhelds or PDAs, in 19% of the projects; 3) Wand or haptic mouse, in 17% of projects; and 4) Game controller or joystick were employed in 8% of projects.

Additionally, different modalities of signal type (visual, audio, and tactile) were observed in the projects: 1) Voice was used in 33% of all projects, 2) gesture in 31% of the projects, 3) computer vision and tracking in 28% of the projects, 4) Sound in 39%, and 5) haptic and kinematics were used in 8% of the projects.

Other techniques observed were: multiple frames of reference, scaling, and search and navigation modes. The navigation modes in 3D space were egocentric, exo-centric, and empath-centric, the latter of which mode used human and/or non-human avatars. Catalogued last are soft user interface elements, such as the use of menus, soft tools, visualizations, and decision support techniques (e.g., the capability to present the past, present and future scenarios).

2.11. Design Patterns and Parameters

The design patterns and parameters found in the reviewed projects are organized in the SEEE taxonomy below (Figure 3). The taxonomy presented is a ***flattened 3D hyperbolic overlapping ontology***.

2.12. The Taxonomy from the Literature Review

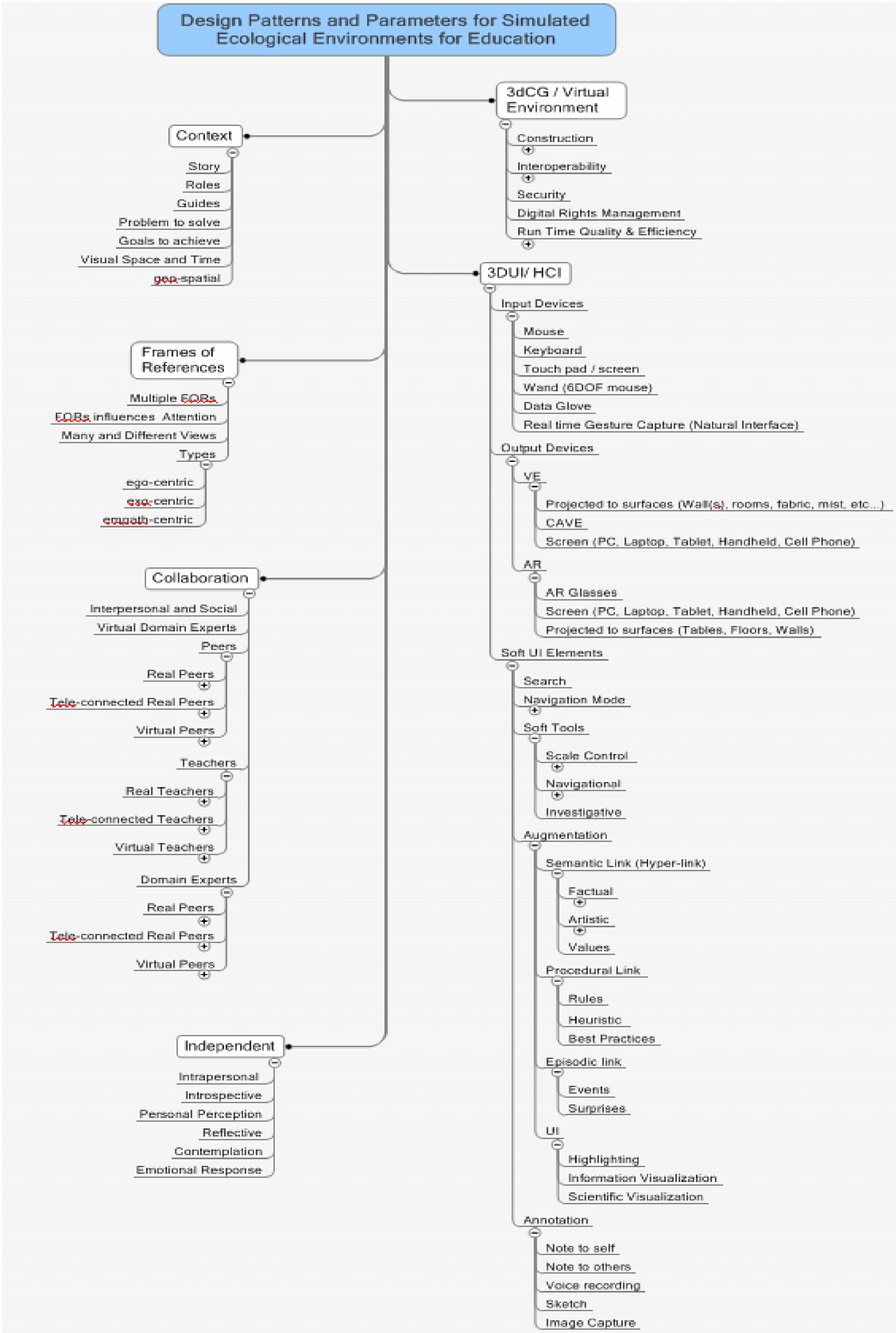


Figure 3: The design patterns and parameters for a SEEE found in the prior literature review.

2.12.1 The Taxonomy as a Hierarchical List

- **Simulation (3D Computer Graphics/Virtual Environments)**
  - **Construction of the model**
  - **3D modeling and rendering engine**
  - **Artificial life engine**
  - **Multi-Modality Components**
    - **Visual**
    - **Sound**
    - **Tactile**
    - **Smell**
    - **Taste**
  - **Interoperability (heterogeneous platforms)**
  - **Security and role management**
  - **Digital rights management**
  - **Run time quality and efficiency**

- **3D User Interface Factors**
  - **Input devices**
    - **Mouse**
    - **Keyboard**
    - **Touch pad / screen**
    - **Wand (6DOF mouse)**
    - **Data glove**
    - **Real-time gesture capture**
    - **Natural interfaces**
  - **Output devices**
    - **Virtual environments**
      - **Projected to surfaces (walls, tables, mist…)**
      - **CAVE**
      - **Screen (PC, Laptop, Handheld, Cell Phone)**
    - **Augmented reality environments**
      - **AR glasses**
      - **Mobile screen (Laptop, Handheld, Cell Phone)**
  - **Soft user interface elements**
    - **Search**
    - **Navigation mode (walk, fly, swim, …)**
    - **Soft tools**
      - **Scale Controller**
      - **Navigational controller**
      - **Investigative controller**
    - **Augmentation tools**
      - **Semantic links**
        - **Factual**
        - **Values**
        - **Concepts**
        - **Artistic**
      - **Procedural links**
        - **Rules**
        - **Heuristics**
        - **Best practices**
      - **Episodic links**
        - **Events**
        - **Surprises**
      - **User interface**
        - **Highlighting**
        - **Information visualization**
        - **Scientific visualization**
  - **Annotation tools**
      - **Notes to self**
      - **Notes to others**

- **Voice recording**
- **Sketch**
- **Image capture**

3D UI Design Factors in Space
- **Context**
  - **Story**
  - **Roles**
  - **Guides**
  - **Problems to solve**
  - **Goals to achieve**
  - **Visual space and time**
  - **Geo-Spatial**
- **Frames of reference (FOR)**
  - **Multiple – FORs**
  - **Influence attention**
  - **Types of views**
    - **Ego-centric**
    - **Exo-centric**
    - **Empath-centric**
- **Social factors**
  - **Collaboration**
    - **Interpersonal and social**
    - **Virtual domain expert**
    - **Peers**
      - **Real peers**
      - **Tele-connected peers**
      - **Virtual peers**
    - **Teachers and guides**
      - **Real teachers and guides**
      - **Tele-connected teachers and guides**
      - **Virtual teachers and guides**
    - **Domain experts**
      - **Real domain experts**
      - **Tele-connected domain experts**
      - **Virtual domain experts**
  - **Individual**
    - **Intrapersonal**
    - **Introspective and contemplative**
    - **Personal perception**
    - **Emotional responses**
      - **Awe and wonder**
      - **Curiosity**
      - **Surprise**
      - **Reflection**

Intelligent Tutor Factors
- **User profile and model**
- **Guided inquiry**
- **Branching and depth**
- **Problem-based**
- **Scaffold-based**

2.13. General Themes

The main categories for success that this research points to are some general themes, such as 1) **context**, 2) **collaboration,** and 3) **multiple frames of reference**. Furthermore, there are the impacts of 4) **visualization** (Dede et al., 1996, 1999, 2005; Johnson et al., 1999, 2002); as well as the sensitively implemented 5) **redundancy gains** (Dede, 1995; Dede et al., 1999) in the multi-signal possibilities of the user interface (Fallman et al., 1999). It also is paramount that 6) **cause and effect relationships** are clear, or students will not be able to learn (Jackson et al., 1998; Jackson & Fagan, 2000) in either the virtual environment and in the conventional educational setting.

2.13.1 Enjoyment and Engagement

Enjoyment, engagement, and increased attention are reported attributes of virtual environments for education. Dede et al. (2005) qualitatively gathered data on the proxy variables of attendance, absenteeism, and the use of profane language of classroom virtual environments, reporting that the results suggest that classroom virtual environments do have a positive effect on enjoyment and engagement levels.

2.13.2 Collaboration

Collaboration with real or virtual peers or guides was shown to reduce inhibitions and increase the desire for, the rate, and amount of exploration (Bobick et al., 1999). Guides are also context-agents, in that they can influence search and navigation strategies, and provide hints or clues for problem-solving. They can even be seen as mentors (Dede et al., 2005). Past research favors collaborative over individual experiences, with the majority of the studies in the category of paired or group work as opposed to those designed for the individual.

In stark contrast to collaborative or competitive systems are systems that are designed for the individual; such systems enhance solitary experiences in ways that are simultaneously engaging, emotional, yet peaceful, tranquil, and serene. The interactive art pieces such as those found at the museum, ALTERNE (2005) were open to individual choice, and The Tent (Waterworth and Waterworth, 2001) as it was originally conceived, was a solo, meditative experience. These kinds of systems represent opportunity in educational applications, especially in designing and building effective systems for the individual.

2.13.3 Context

Virtual reality can be confusing; if a proper context is not established, little, or no, learning may result. Context decreases complexity and may provide affordances and framing, thus improving the student's ability to focus on the important material in the intended way. Context in virtual environments for education can be achieved in many ways, such as with a story (Alborzi et al., 2000; Billinghurst et al., 2001; Bobick et al., 1999; Braun, 2003; Dede et al., 2005; Looser, Billinghurst, & Cockburn, 2004; McKenzie & Darnell, 2003; Roussou, Johnson, Leigh, Vasilakis, Barnes, & Moher, 1997; and Roussou, 2004); context is also provided through role usage (Johnson, Moher, Ohlsson, & Gillingham, 1999; Cho, Moher, & Johnson, 2003), or by giving the students problems to solve or a goal to achieve (Cho et al., 2003; Dede, et al. 2005; Johnson et al., 1999, 2000: Johnson, Moher,.Ohlsson, & Leigh, 2001; Johnson et al. 2002; Mikroopoulos et al., 2003; Poland, la Velle, & Nichol, 2003). Visual context, such as that used in the eyeMagicBook (McKenzie & Darnell, 2003) and The Geist Project (Braun, 2003), can, with the other context-providing devices, show positive results in by supporting efficient navigation.

Many of the scientific applications had problems to solve, as did Project Science Space (Dede, 1995; Dede et al., 1996, 1999; Salzman et al., 1996, 1999) and Global Change World (Jackson & Fagan, 2000). Problem-solving contexts were also found in the Round Earth Project (Johnson et al., 1999)., The Field (Cho et al., 2003; Johnson et al., 1999, 2000, 2001, 2002;), MUVEs (Dede et al., 2003, 2005), Virtual Environment in Biology Teaching (Mikropoulos et al., 2003), the Virtual Field Station (Poland et al., 2003), and in the subtle, delicate, and elusive uses of the goals, "to go and explore and reflect" in

The Ambient Wood Project (Rogers et al., 2005; Weal, Michaelides, Thompson, & De Roure, 2003) showed results.

The visual context was a universal component in all of the applications. The constraints of the environment in the form of visual cues, such as routes, trails, paths, and landmarks, were not found in the literature. Perhaps one of the most interesting projects was the DigitalEE II (Okada, Yamada, Tarumi, Yoshida, & Moriya, 2003), with its implementation of the collaborative construction of a shared frame of reference necessitated by co-wayfinding, co-attending to objects of interest, and communication between real and virtual travelers with the subtle goal of appreciating nature. The user interface facilitated those unique activities with the *Shared Eye* (Okada et al., 2003). This project demonstrated how a UI (a tool) could be used to collaboratively construct a shared view of reality.

2.13.4 Frames of Reference

Providing multiple frames of reference, both under user control and designer-selected, is yet one more common thread that has been shown to improve learning and minimize confusion (Salzman, Dede, Loftin, & Ash, 1998). As has been found in scientific visualization software, independent exploration and understanding of the information is enhanced with multiple frames of reference and meaningful layers of abstractions. The Project Science Space MaxwellWorld, (Dede, 1995; Dede et al., 1996, 1999; Salzman et al., 1996, 1999), DigitalEE II (Okada et al., 2003), The Round Earth, (Johnson et al., 1999), and the MUVEs work (Dede et al., 2003, 2005) — all of these projects strongly indicated the benefits, as all showed knowledge gains.

Furthermore, since these virtual environments are constructs, the designer can intentionally select a visual frame of reference to increase the probability that the student will attend to the educationally important information in view. Often, by providing a user interface with multiple views of the information, understanding can be improved (Okada et al., 2003). This is yet another area for future research.

2.13.5 Emotion

The interesting theme of emotion and the relationship to skill enhancement, observation, an increased sense of awe and wonder was explicitly stated by several of the research efforts. The most notable was The Ambient Wood project (Rogers, et al., 2005; Weal et al., 2003), the DigitalEE II (Okada et al., 2003), The Tent derivative (Green, Schnadelbach, Koleva, et al., 2002), and to some degree, the MagicBook (Billinghurst et al., 2001), MagicLenses (Looser et al., 2004), and eyeMagicBook (McKenzie & Darnell, 2003) projects. This emotional reaction is yet one more cognitive motivator to investigate in educational software design and user interface design.

2.13.6 Knowledge Gain

Research has shown that learning does occur in virtual environments, yet the atomic causal variables, their combination and measurement, are still unknown. Previous research has not investigated or reported on the exact, measurable factors or attributes that the 3D image has had on knowledge gain, and so part of the research plan will be to investigate the exact impact that each visual attribute may have. Furthermore, the previous research has not isolated the exact areas in which the object's context may impact the amount of knowledge gained. Lastly, the combined impact that image quality, context, and free choice has had on knowledge gain has not been tested empirically, thus the aim of this research is to extend the previous work in these trajectories.

2.14. Heuristics for Designing and Testing Simulated Ecological Environments for Education (SEEE)

In addition to the general themes discussed, one can also identify specific heuristics that can be used when designing a virtual or simulated environment for education (Harrington, 2006a). The following list of heuristics and best practices was extracted from previous research. The framework expressed in Figure 5, The SEEE Tripartite Model, shows the three elements of knowledge domain, the virtual environment, and the user interface. These three elements are used as the main categories in which to organize the heuristics below.

2.14.1. Educational Research Design

a) Use a control group.

b) Use pretest, posttest, and log activity.

c) Know what to measure (causal, independent, and dependent variables) and how to measure it before the experiment.

d) Define a rubric or ontology of the information, both declarative and procedural.

e) Can the activity be compared to a group that learns the concept in the traditional way? If so, design the experiment to assess the gain. Is it better than the current method?

f) Separate content (educational material) from form and function (virtual environment and user interface). Decompose and measure the impacts of each.

g) Children paired with peers, a parent, a teacher, or in collaborative groups of trustworthy friends will reduce inhibition about completing exploration tasks.

2.14.2. Simulation and Virtual Reality

a) If interacting with Artificial Life, make the models look and behave real.

b) Designer-selected frame of reference views will influence what the user attends to, so choose carefully and deliberately.

c) Scale, either very small or very large, can be used to advantage in this medium.

d) Routes, landmarks, and textured regions facilitate egocentric way-finding, but when the level of detail is too low, the children will fail to navigate in a meaningful way; therefore, provide exocentric views.

e) Provide context of all types.

2.14.3. User Interface

a) If possible, make it true 3D, stereoscopic.

b) Use natural interfaces, such as voice recognition and gesture.

c) Use a large CAVE /DOME with controls that facilitate unencumbered interaction, or a standard desktop with controls that the children know how to use.

d) Interaction must be real time without lags.

e) If using sound, it should be spatial, and the sound should be perceived as being emitted from the direction of the source.

f) Use scientific visualization to show data that cannot be seen.

g) Carefully use multi-channel redundancy gains but not to the point of creating noise.

h) If a user becomes the avatar or object, allow for the adoption of multiple roles or frames of reference.

i) If a user is alone, have a guide or avatar available for help.

j) Cause-and-effect relationships must be very clear in order to foster learning of correlations in the virtual environment, user interface, and the content material.

2.15. Literature Review Conclusion

The review suggests that context is important for such systems to be successful, whether it consists of a story to follow, a role to play, a problem to solve, or a landscape to explore along a trail. It also seems clear that the quality of the user interface can impact the success or failure of such systems. The user interface in terms of the hardware, software, and the underlying models and simulations, as well as the intelligent tutors, is important to consider. The user interface is the combination of the content and the augmentation, form and function.

Future work will focus on building, testing, evaluating, and improving models for these kinds of systems. Of high importance will be the user's task: the task of a child engaged in situational learning. Keeping the focus on the users' task will further the purpose of finding and quantifying the interplay between the design of the simulation and user interface, and how those design parameters impact attention, curiosity, inquiry, and learning of scientific material or acts of creation for the child.

3. Dissertation: A Complex Ethnographic and Empirical Investigation into Simulated Ecological Environments for Education and the SEEE Theoretical Framework

This chapter fully describes the problems and the theoretical framework surrounding those problems from both the Learning Sciences and Information Sciences perspective. It is a general set of questions that help the reader understand the broad picture, but not the detailed statistical questions, which are presented in other chapters.

3.1. Overview

This dissertation began with several observations. First and foremost was the observation of my daughter as she learned about science and ecology on a field trip to a local wildflower reserve, which created a research interest in situational learning. Second, the observation that the technology paradigm shift in computer graphics was producing low-cost, high-end computer graphic simulators in the form of a video games (Jacobson & Lewis, 2005) and free online virtual environments (There.com and Secondlife.com). Third came an interest in visual and perceptual theory, especially in perceptual ecology by J.J. Gibson (1979).

The opportunity to create a new user interface for education is now possible. This interface is spatial, temporal, episodic, semantic, emotional, and aesthetic. I selected ecology as the content area, for it offers the most opportunity for spatial cognitive and situational learning research in the framework of ecological psychology. We now can build a realistic copy of the environment and test with very high internal validity, as it is a statistically identical model of the world. Additionally, the 3D computer graphics allow very high precision in measurement, as it is a mathematical world that is fully instrumentized.

Other important selection criteria behind my electing, as a VR scenario, a field trip to a nature reserve was based on very pragmatic software development goals. For the student, nature and field trips are fun and lovely, and for the software developer, trees and flowers—unlike animals—do not move. Science curricula and content are well-established and easy to leverage. Data from the wildflower plant population, gathered by Dr. Susan Kalisz over the past 15 years, was made available to the project. The Audubon Society of Western Pennsylvania allowed their curriculum to be used and participated in the activity analysis of the first qualitative study. The local school teachers were very helpful in donating time and expertise to review the system, curriculum, activity, and the pretests and post-tests. The Commonwealth of Pennsylvania had just recently released, under No Child Left Behind, new science and technology and ecology standards.

These factors combined with market forces that made high-end game engines affordable and available for research into simulations, spatial cognitive ecologies, and user interfaces for education and learning. These environments are referred to as Simulated Ecological Environments for Education (SEEE) and open research questions into the user interface design factors that result in learning. The research aim of this dissertation is to produce both qualitative and quantitative evidence that can inform good HCI design of such systems. My goal is to develop practical, empirically grounded theories of HCI design, which will make it possible for educators and user-interface designers to produce high-impact learning simulators for children.

3.2. HCI Focus on Children's Needs

It is assumed that software should be designed and built with the goals of the user in mind. In the field of Human Computer Interaction (HCI), one tries to create usable, natural, efficient tools for a variety of user profiles, goals, and tasks, with a wide variety of tools and approaches in a wide range of contexts and environments. Some needs are cognitive augmentation, information retrieval, knowledge acquisition, and visualization. Other times, we may create tools to facilitate visualizations, decision support, and creativity (Harrington, 2006a).

Educational computer software systems are created for children with the goal of teaching and learning in mind. Throughout the 1990s, encyclopedic data and information was made more visually realistic with the application of new types of user interfaces, those that offered graphics, multi-media, video, and visualizations, thus increasing the range of the ***visual fidelity.*** Very recently, due to advances in computer hardware processing power, we have a new technology paradigm in computer graphics, that of real-time, interactive 3D virtual reality, simulations, and visualizations, thus extending this range even further. Additionally, in the 1990s, the style of navigation was changing because of the adoption of hypertext, and so this dimension, of choice in navigational direction, became standard, and increased the range of the ***navigational freedom.*** Currently, with the merging of computer-game technology and educational technology, we have a new paradigm in educational interactive systems for the user interface. A virtual 3D environment is one where the navigational degrees of freedom approach infinity, and they are completely under the user's, not the programmer's, control. The technical aim of this research is to ***investigate the factors that cause an event of inquiry resulting in knowledge gained, with respect to the visual fidelity scale and the navigational freedom scale, and to determine if there is any interaction between these two factors***.

Other key concepts for this research are emotional states and perceptions of beauty, such as the sense of "awe and wonder" and response to the aesthetic quality of the images, and how these very difficult and subjective concepts can be tools to the user interface designer. How do user interfaces affect user experience in the emotional and aesthetic dimensions? How do emotion and aesthetics affect inquiry, exploration, knowledge gained, and creativity? Other user interface functionality, such as curriculum quality, and teacher or intelligent tutor expertise, are related, especially for a commercial product, but are considered out of scope for this dissertation study. We assure that they are of high quality, high factual accuracy, and held constant in the studies for high internal validity.

Examples of emotional dimensions are in the ranges of boredom to excitement, fear to safety, disgust to awe and wonder, just to name a few. This research attempts to hold constant, and at a high level, the emotions of excitement, safety, awe, and wonder for enhancement of the child's emotional engagement and experience. The user interface is discussed in terms of visual fidelity and navigational freedom. These UI parameters and how they contribute to learning constitute a rich area for future research. Furthermore, the curriculum range will be held constant across all conditions, containing the facts, concepts, values, and lesson-plans found in the real field trip learning unit, *Natural Communities* (Beechwood Farms Nature Reserve, 2005). The set of data from the real learning unit was expanded with the expert knowledge of the O'Hara Elementary School Quest teachers, the educational staff at Beechwood Nature Reserve at the Audubon Society of Western PA, as well as the incorporation of the expert knowledge of biologist Dr. Susan Kalisz. As the state standards were a subset of the school and the Audubon, we did not concern ourselves with the standards. It was of critical importance that the set of facts in the system matched the plot study data of the Trillium Trail's real-environment ***deer exclosures*** data sets (Kalisz, 1996-2006). All of the data, information, and lesson plans were integrated to create the content ontology for the experimental systems. There is information on 102 plant species in the Trillium Trail geospatial database, not to mention general plant and flower facts, site-specific geographical information, and some interesting semantic, historical, medicinal, and artistic factoids about each plant.

The teacher and collaborative peer-to-peer dimensions are excluded from this empirical comparison, as they introduce unnecessary levels of complexity to the programming and the research design. Most importantly, this research is concerned with the factors that cause perceptual and cognitive ecological event(s) that result in independent, intrinsic exploration and inquiry. Thus exists, the opportunity for others to investigate the role of socially motivated inquiry.

The theoretical aim of this research is to investigate the causal events in the user interface as it represents a computerized, synthetic perceptual and cognitive ecology. These events are either ***user-driven and intentional*** or ***simulation-driven and spontaneous***.

Furthermore, these variables, when combined with other variables from other dimensions, may or may not have threshold points, may or may not have discrete values, or may or may not have ranges that are dependent upon the mix of interactions with others. These ranges are expressed in this research as scaled values, ideally from the ***minimum value*** to the ***maximum value***, and may be sensitive to combinations or convolutions of many signals. However, since we do not yet know the minimum or maximum value, we will start with a high and low value for this initial research study.

The designing of intelligent tutors has been well explored (Biswas, Katzlberger, Bransford, & Schwartz, 2001; Mathan & Koedinger, 2005) with system ontologies based on curriculum and navigation based on scaffolding techniques (Cho et al., 2003). Adaptive hypermedia with personalization has, for its part, been well-developed (Brusilovsky, 2002), as have ways to access procedural and declarative knowledge via cognitive models of the student (Anderson & Lebiere, 1998). Other research has focused on the development of stochastic algorithms and Bayesian networks (Conati, Gertner, VanLehn & Druzdzel, 1997) applied to *coached problem solving* (VanLehn, 1996). The other approaches have dealt with game-and problem-based strategies, where external conditions were used to motivate users (De Aguilera & Mediz, 2003; Egloff, 2004; Jacobson &vLewis, 2005; Jenkins, Klopfer, Squire, & Tan, 2003).

One approach to this problem was to investigate the idea of an avatar guiding students through the virtual woods. The avatar could be a famous environmentalist and scientist, Rachel Carson (Carson, 1962). Originally, the thought that an inquiry-based learning system with a natural language interface (or at least pre-recorded answers as a voice file for redundancy gains) would be the solution desired, similar to the story-based work found in the *Geist* project (Braun, 2003), which featured an adaptive story-telling avatars. The other approach was in the use of inquiry-based learning, such as that used in the Jasper Woodbury videodisc work.

However, and ultimately with the direct activity study, the students really were interested in all of the other things in the woods, too, especially personally salient things or personally meaningful things. One of the pre-dissertations observations, consisted of a day spent studying birds. It was raining, so we did not see a single bird. Nevertheless, we did see a bullfrog, a turtle, a snake in a tree, and many more plants and animals (the full activity study is in Appendix A). Also noticed, was that the children required about 20 minutes in the environment before they reached a state of perceptual-emotional engagement. It became obvious that it was not the student-teacher relationship that was to be the core of the dissertation research, but the environment, and the model of the ***child-nature relationship.***

3.3. Framing the Problems

3.4. The Problem Definition for Education

The following research questions are important for education:

1. Can a tool be developed that approaches the educational experience found in the ideal relationship between a child and an expert naturalist guide on the trail?

2. Can we intentionally design a tool that will inspire a sense of awe and wonder?

3. Will such feelings lead to more facts learned, deeper knowledge, and acts of creation?

4. Can a tool be developed that will exceed the educational experiences offered by the best-case scenario in the real world? How can classroom work be reinforced by showing inaccessible locations, such as nature reserves that are too remote for practical field trips, or by showing inaccessible ecosystems and species that are not to be found or are no longer in existence? Can such a tool make distance and time barriers disappear in the face of new kinds of learning?

5. Can such a tool be designed to intentionally direct attention and support inquiry with augmentation that increases the impact of the learning environment in positive ways?

6. Can we support individual exploration and intrinsic inquiry in a high- fidelity simulated ecological environment?’

7. Can such simulated ecological environments be used to increase islands of expertise? Can they increase vocabulary, declarative knowledge, conceptual knowledge, schemas, and personal memories?

8. Can we create salient events that trigger intrinsic learning?

3.5. The Problem Definition for Information Science

The philosophical bases for these ideas were seeded by J.J. Gibson (1979), Green & Swets (1966), and Epstein & Axtell (1996). It is not just a ***perceptual ecology*** (Gibson, 1979) but also a ***cognitive ecology*** (Crowley, 2005) that is of interest. Central to this research is investigating the interplay of salience, semantics, emotions, and memory in a natural spatial environment, interdependently linked to an internal cognitive model of a child involved in the task of learning. Why does situational learning work? How can an application be designed to support the child in this activity? From a Human Factors and cognitive perspective: What are the parameters for a successful experience as compared to an unsuccessful experience? Can experience be measured? Quantified? Applied to future designs? Thus, the main information science question is the quantification of the interplay of salience, semantics, emotions, and memory in spatial situational learning.

3.5.1 Interplay of Salience, Semantics, Emotions, and Memory

- Human Factors and Cognitive perspective
- WHY does it work?

Some of the advantages of a Simulated Ecological Environment include having a model that is perceptually and cognitively representative of the real environment, and as such, is an ideal environment in which to isolate parameters, variables and attributes for Human Computer Interaction research. In addition, since it is created in a computer, the models can be expressed exactly and mathematically. Objects are 3D geometry, colors are indexed, and therefore, exact measurements can be obtained to describe the signal in terms of hue, saturation and brightness, height, width, volume, and even motion, captured as the distance moved. Sound can be captured quantitatively and thus measured as well. The semantic content can be captured and measured as an indicator of the knowledge in the system, and captured and measured as a percent explored and learned by the student. Fortunately, in the biological sciences, taxonomies and ontologies exist, with exact definitions in ecology and biology, on which to base the semantic knowledge measurements. Just how the student responds to the ambient array of multi-channel signals is now possible.

The user tasks of searching, navigation, and inquiries can be logged, and thus measured. Duration, reaction time to events, depth of search or exploration, breath of search and exploration, interlaced patterns, and information selected for query can be captured and measured. The user's ***exploration in context*** can be permitted and measured with a high degree of realism, relevancy and accuracy, provided that all of it is logged,—every mouse click, drag and keystroke, and frame of reference, as well as the external context including the ***negative space*** (Bachelard, 1958)***.***

Augmentation of the interface can be empirically researched along several dimensions. The designer can use a label, a sound, a surprise, and highlighting effects. Since the user interface is also created in the computer, it is measurable, possessing its own set of parameters, variables, and attributes as the quantified dimensions of the UI.

3.5.2 HCI Interplay with the Virtual and Real Environments

- Search, Information Retrieval, Navigation, Augmentation
- HOW does it work?

The image that is presented to the user may be thought of as a ***convolution of many signals***. Is there statistical interaction? In this research, it is presumed that a multi-layer signal can be decomposed, by recording the source signals, then measuring and relating these signals to the user's level of attention, exploration, and knowledge gained. Signal Detection Theory (Green & Swets, 1966) is a general framework that can be used to quantify the observer's sensitivity, which is determined by the ratio of signal (distance between the distributions) to noise (standard deviation of the distributions) within the system (Gold, Seculer, & Bennet, 2004). The following conceptual diagram shows a few of the variables that could be presented in the three layers: 1) virtual environment with an 2) augmented user interface and some 3) cognitive variables for a child. What is strikingly different about the following graphical representation of this model is that the

***boundaries between the signals in the virtual environment, the signals in the user interface, and the cognitive signals blur into one networked graph*.**

Furthermore, should the augmented user interface use all variables (motion, edge enhancement, maximized field and ground signal-to-noise ratios, and semantic, audio, emotional surprise), then will the augmented user interface have a salience index in addition to the virtual environment's salience index, possibly compounding the signals' strength? Does this result in deep learning, or just noise? How do each of the aforementioned variables contribute to conceptual changes in the learner's mental model?

1. How do these layers of user interface interact? Is it possible to decompose the total signal into its atomic variables? Can the attributes be isolated and measured?

2. Is the combined effect linear or exponential, additive or subtractive for learning?

3. Does a child's learning style, previous knowledge, and memories impact this model? If so, how? What are the layers' variables' or attributes' magnitude on conceptual change?

4. What impacts do the layers, variables, or attributes have on the factors of time spent exploring? Are longer exploring times related to enjoyment? Deep learning? If so, how do we factor in the child's breadth and depth of navigation?

5. Can independent acts of inquiry, as measured by mouse clicks on links, be regarded as intrinsic learning. Is it lasting? If so, for how long?

6. On average, how much knowledge gain is measured in the difference between the pretest and post-test of knowledge as compared to traditional instruction and tools? Is it as good as that related to a real field trip? If not, then by how much is it inferior? Is it better than the traditional computer-based training programs currently in schools? If it is superior, then by how much?

In order to answer any of the information science questions, it will be important to measure in-experiment the attributes of the variables of the scaled ranges. For example, the image of a flower could be decomposed into attributes of color, and color could be decomposed into attributes of hue, intensity, and saturation. Another example could be a label that can have a size, font, color, hyper-links and highlighting and ontological relationships and definitions, as well as proximity of location to the image.

3.5.3 Causal Graph of SEEE Variables and Attributes

The following (Figure 4.) is only a conceptual sketch on how SEEE can be used to measure correlations, build multi-variable regression models, neural networks, or Bayesian networks between the layers. The Research Design highlights all of the dependent and independent variables in detail.

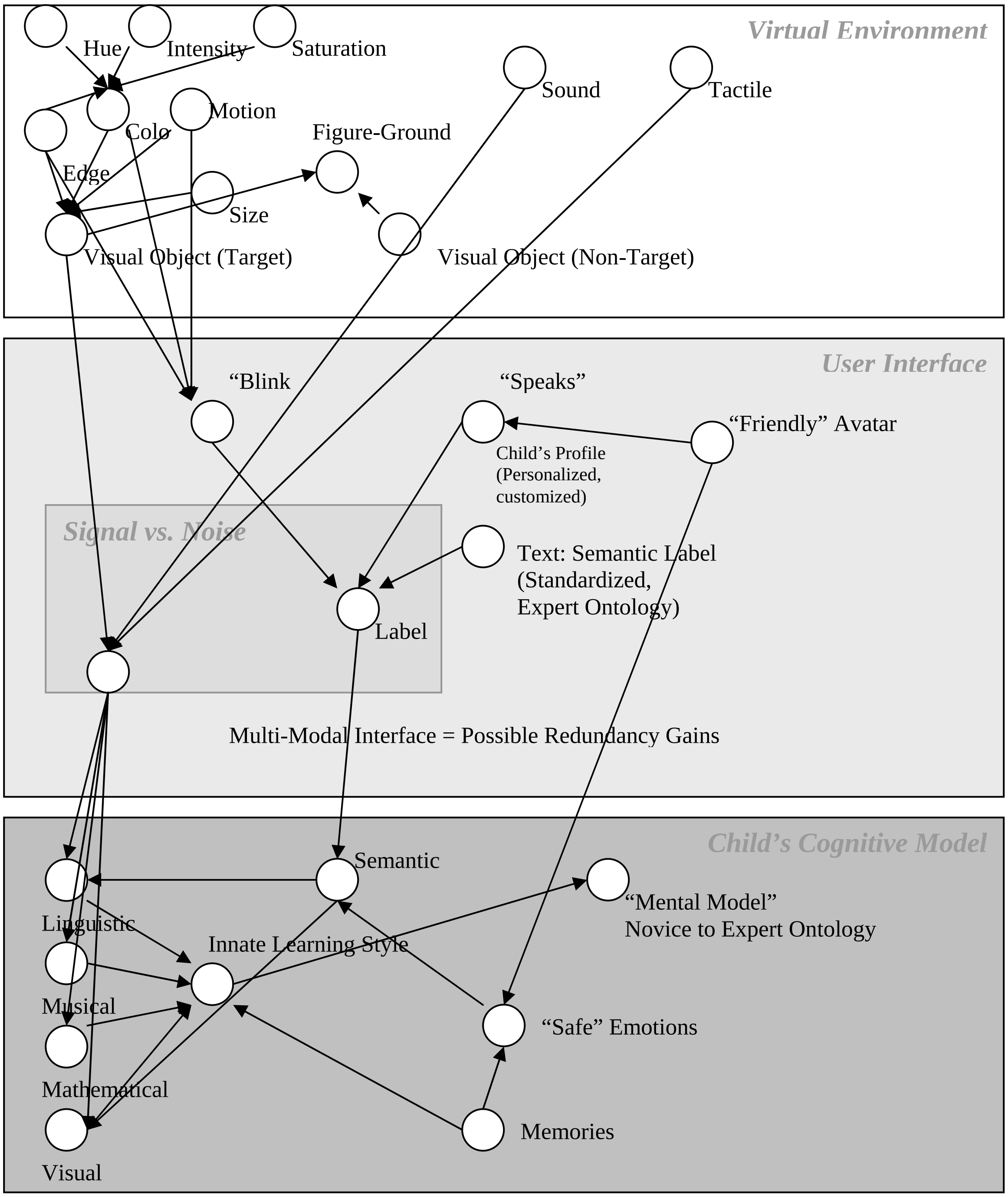


Figure 4: Conceptual graphical representation of a causal graph for SEEE atomic salience model.

3.6. Syntheses of the Framed Problems

3.6.1 Definition of SEEE

The SEEE research is more concerned with the events that trigger a desire to learn about the environment, than with the underlying intelligent tutoring system. The SEEE is a "cognitive tool" for augmentation, and for the facilitation of the child's curiosity – like a very powerful field guide, encyclopedia, compass, notebook, binoculars, and sketch-pad – all under the child's control. The experience is intended to be like a spontaneous adventure, without a story, without pre-fabricated learning goals, and one that is open to the child's innate desire to explore and learn.

The SEEE does not exclude intelligent tutoring systems or inquiry-based learning, as they can be separate system components and integrated in future implementations. The first prototype was to focus on the ecological and cognitive events, such as salient, beautiful, and emotional events that could trigger the choice to inquire. After the desire exists and the inquiry is made, there are many ways to program the system response and the presentation of the answer.

The SEEE is an "informal," information and knowledge acquisition system. Extending the 1961 Debons EATPUT model (Debons, Horne, & Cronenweth, 1988), the SEEE is a nonlinear, recursive system. The EATPUT components of 1) Events, 2) Acquisition, 3) Transmission, 4) Processing, 5) Utilization and 6) Transfer are all present in the SEEE. Either the entire SEEE can be viewed in the EATPUT metaphor, or it can be seen recursively, with each node viewed as an EATPUT system.

Simulated Ecological Environments for Education (SEEE) is highly realistic in image, spatial layout, function, and purpose. A SEEE is constructed from geospatial data sets, biological plot studies, and scientific data, facts, concepts, and values. It is statistically ***identical*** in every way to the real environment. It can even be augmented with custom-made landmark species to increase the level of realism and to facilitate way-finding. It is modeled after a real environment, such as one found in nature.

That the SEEE be based on reality is a key requirement. Since the designer has the power to create a fictitious model, learning in a non-factual, fictitious, and distorted model may introduce misconceptions. Other requirements are that the model have aesthetic integrity to capture the object's spirit, and the semantic facts, concepts, and values are self-exposing attributes of the 3D object. The next requirement is that the model is augmented with meaningful abstractions and schematics or sketches for clear visual communications. Access points (hyperlinks) should exist to related data, information, and knowledge such as books, songs, poems, artworks, maps, and video to facilitate the horizontal linking of information. The point is that it is a cognitive tool and simulation, not a game, with the primary goal of supporting the child in independent exploration and inquiry for learning tasks and goals that should drive the design and development of the SEEE. The SEEE embodies in objects knowledge that is accurate, complete, and easily accessible at will. Lastly, that like an ideal relationship between an expert guide and a child, the user interface should augment the model in ways that support knowledge gain and procedural strategies, gracefully moving the child from novice to expert in both domain and procedural knowledge at the child's pace, level, interest, and way-finding preferences, without guide direction or domination.

3.6.2 Child's Cognitive Model

Of primary concern is how young children, in the K-5 school grade age bracket, learn and how tools can be designed to support and empower them. Their unique informational needs for learning are considered. Children are unique as a user group in that they freely engage their imagination and creativity, and are often naturally inquisitive, fearless explorers who are intrinsically motivated to learn about their environment. In addition, they have not yet been saturated, as have high school or college-age students, by the ambient array found in popular culture. They seem to absorb everything, correct or not, biased or not, appropriate or not. Violent games have been shown to be correlated with aggression and destruction (Dill and Dill, 1998). Could not peaceful games be shown to be correlated with peace and creation? Thus, the software execution that supports intrinsic, independent exploration for information, knowledge discovery, and acts of creation will be of primary concern.

3.6.3 Simulation & Virtual Environment

The knowledge embodied in the visual content focuses on the natural world. The possibilities of the current technology allow for the creation and maintenance of fully-simulated, real-time, dynamic, and accurate data based models of nature. The future direction is towards an accurate, dynamic world in miniature, where high-fidelity simulations of plants, flowers, trees, insects, and animals are all components or artificial intelligent agents (actors or avatars) within natural, interdependent, dynamic relationships (Benes, Cordoba, & Soto, 2003; Bishop & Gimblett, 2000).

Some virtual reality projects that required autonomous avatars, such as the virtual gorillas (Allison et al., 1997) have focused on building simple artificial life (AL) models for the required behavior. Others have solely focused on the underlying quantitative models to accurately simulate appearance for non-interactive computer graphics and can be thought of as off-line simulations. Yet others have focused on technical solutions for real-time dynamics of the simulation.

Some of this research has focused on the models and simulations of entities such as: flowers growing (Prusinkiewicz & Lindenmayer, 1990; Prusinkiewicz, 2000, 2004), meadow formation (Deussen, 2003; Deussen, Colditz, Stamminger, & Drettakis, 2002), ecosystems, (Deussen, Hanrahan, Lintermann, Mech, Pharr, & Prusinkiewicz, (1998), leaf venation patterns (Runions, Fuhrer, Lane, et al., 2005), real-time, interactive plant leaf rendering (Wang, Wang, Dorsey, Yang, Guo, & Shum, 2005); forces of nature and dynamics in fire, smoke, and water (Losasso, Gibou, & Fedkiw, 2004; Selle, Rasmussen, & Fedkiw, 2005), ocean surfaces (Johanson & Ledfors, 2004), illumination and photorealistic atmospheric phenomena and clouds (Ebert, 2003), ants and ant colony behavior (Dorigo & Stutzle, 2004), bees dancing (Johnson, Moher, Cho, Edelson, & Russell, 2004), fish swimming (Frohlich, 2000; Terzopoulos, Rabie, & Grzeszczuk, 1996), wolves dominating, submitting, and attending (Tomlinson, 2002), synthetic characters that convey the illusion of being alive (Torres & Boulanger, 2003), and people in all sorts of roles, from historical figures to ghosts (Braun, 2003). But, to be believable, the content must move, behave, react, and autonomously act in a realistic fashion.

Resembling virtual reality user interfaces, simulations and Artificial Life (AL) applications can be thought of as horizontal applications, independent of the user interface. Artificial Life and Simulations can be studied without high-fidelity user interfaces. The premier research in AL (Epstein & Axtell, 1996) had an abstract and simple user interface, represented visually as only dots on a grid in The Sugarscape Model. One key assumption, is that for educational simulations to work for young children, the user interface and visualizations need to represent concrete realistic objects, not abstractions. Those visualizations, simulations, if representing dynamic, living, interconnected, and synergistic relationships and interactions, have to be revealed to the student in a realistic and truthful presentation in those virtual environments. This is required so that the connections may be directly observed and discovered by the student. Otherwise, the student may incorrectly infer and draw false conclusions that would increase the probability of producing an erroneous mental model.

3.6.4 User Interface and Augmentation

The user interface paradigms within these environments are unique, and to some extent, represent experimental techniques (Bowman, North, Chen, Polys, Pyla, , & Yilmaz, 2003; Darken & Sibert, 1996). The systems that support the independent, intrinsically motivated learner, and the ones that support exploration and knowledge acquisition in a three-dimensional space are the last focus of the synthesis. Additionally, the main categories of any user interfaces—search, navigation, and augmentation— will be examined in this context.

The other conditions on the user interface design will be directly or indirectly related to the task interaction with the plants, animals, nature, and or ecology. Scientists' tasks require the use of data visualization to explore large data sets (Puget Sound, 2005). They require augmentation and other tools (Bowman, et al. 2003; Bowman, Gracey, & Lucas, 2004) for exploration, pattern identification, seeing correlations, and making discoveries. Some of these activities, tasks, tools, and ideas may transcend into an educational tool set requirement for children engaged in intrinsic learning.

The issues unique to user augmentation and creation will also be considered as a final supporting technology to facilitate learning, understanding, and knowledge acquisition. We know we have deep knowledge when we make it our own, either through talking with others, writing about it, or making scientific models or works of art. Educators often refer to this as transfer, synthesis, and evaluation (Bloom, 1956), yet the final step creation is not discussed by Bloom, and is viewed as an important last step for the child. How to support the child in this final step is of high importance, and thus the need to support creative acts such as those found in act of journaling, drawing, songs, drawing, painting, and dramatic play.

The following diagram, Figure 5. The SEEE Tripartite Model, exhibits the main components in such a system design space, suggesting the potential interrelationship between the child, the virtual environment (VE), and the user interface (UI). It also presents a model of the relationships between the nodes, see Figure 6. The ideal system for a SEEE should support interactions as they are presented in Figure 6.

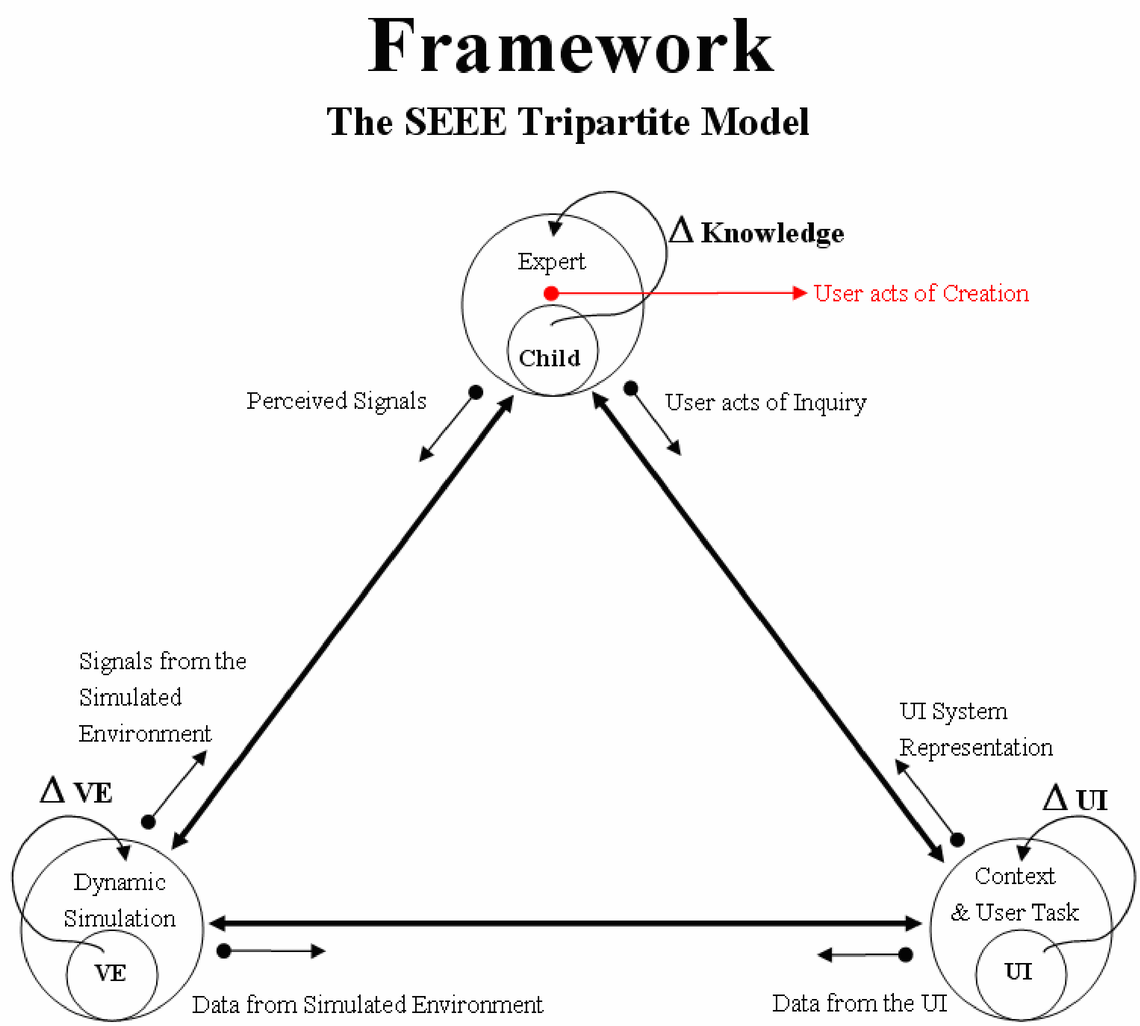


Figure 5: The SEEE Tripartite Model. A conceptual framework and a possible Markov Model.

3.6.5 Dynamics of SEEE

Changes in the child's knowledge (Δ Knowledge) are represented in the framework shown in Figure 6, as a novice's ontology of the domain, a subset of experts', which, after interacting with the simulation (VE) and the user interface (UI), may iteratively expand outwards and towards the experts' ontology of the domain, represented in Figure 6. as the larger circle (Δ Knowledge). This larger circle in Figure 6. represents the experts' knowledge, where the declarative knowledge is the domain ontology and the procedural knowledge represents the experts' algorithms (rules) and heuristics. The expert domain knowledge can be represented as an ontology in a knowledge acquisition system. Changes in the virtual environment result in new visual signals for the child to perceive. New signals present opportunities for the child to either recognize (accessible in memory) or not recognize (not in memory); that is, it is the opportunity to inquire. The *active*, *chosen act of inquiry*, based on the child's understanding that they do not know, is a user-initiated action or a set of actions via the UI, requesting semantic information about that visual signal. This is *active user-initiated inquiry*, which is different from a *passive reception* of new information about an unrecognized visual signal, and is a very important distinction for this research. Since we only perceive what we can see and know to look for, we need to recognize unknown signals and seek to know them. Does this cognitive process require some sort of Meta-Perception support tool, a UI for improved perception?

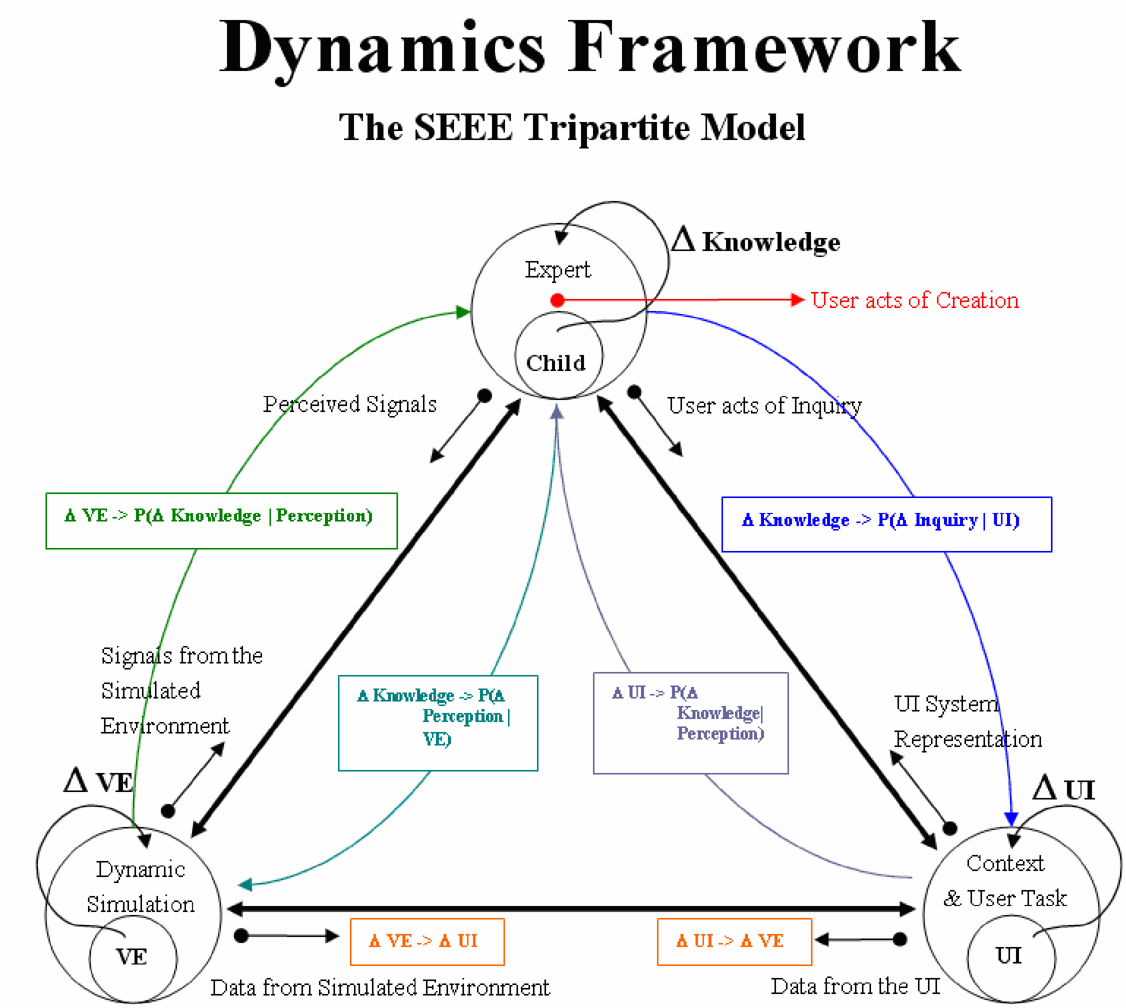


Figure 6: The SEEE Tripartite Model. A conceptual framework and a possilbe Markov Model.

The SEEE UI is designed to enhance the perception of signals (various redundancy-gain UI techniques such as highlighting and scientific visualization) and to intentionally capture the user's attention. Very much like an art student being trained to actively and consciously observe, see, and analyze the visual object, then to re-create it as artifacts, check it for error, and iteratively reduce the error, the UI should support the user in learning to see more actively and consciously the details in the VE. The UI can use various abstraction techniques to highlight important information, direct attention, and reduce cognitive overload.

4. Transferring the Problems and Framework into Research Aims

The dissertation SEEE Theoretical Framework is here transferred into system and research design frameworks. Introducing and justifying the operational goals required to achieve the research goals are connected to the empirical aim of this research, which is to investigate the factors that cause an event of inquiry resulting in knowledge gained, with particular respect to the degree of visual fidelity and navigational freedom available to users within a simulated ecological environment for education.

The prior research shows that knowledge gains and enjoyment are results of virtual environments for education, but not the causal factors. The theoretical analysis of the literature and prior research shows that context, social collaboration, frames of reference, and emotions are powerful and common conditions required for knowledge gains and enjoyment (Harrington, 2006a). As important as these generalizations are, we believe that more precise heuristics and HCI design guidelines can be determined.

The open theoretical questions deal with the set of factors, or ecological events, that cause an independent emotional reaction and desire to explore, inquire, learn, and create. The HCI design problems deal with software design parameters that can influence the ecological events, the child-computer interaction, and the usability and subjective satisfaction of the experience. Answers to such design problems are needed to inform HCI trade-off decisions for such child-centric learning environments. What are the design parameters that affect or influence the outcomes of in-situ activity for intrinsic exploration, inquiry, learning, emotional enjoyment, and the desire to record or create?

While there are many studies on collaborative or guided scientific inquiry in real, virtual, and simulated environments, there are few that study the interplay between the design of the simulation and the user interface. The main research aim is to decompose the simulation and user interface into the design parameters that influence perception, exploration, inquiry, learning, and a range of emotional reactions and motivators, such as curiosity, awe and wonder, and beauty. The research design investigates what tools support independent exploration of a space, enhance deep learning, and motivate creative or scientific inquiry. A major interest is in the role that ecological context plays in the perception of spatial information.

The main objective of this research was to investigate some very complex problems in learning and its relationship to the environment. Furthermore, the initial problem of how to approach and frame the correct questions was daunting. The first set of problems center on the perceptual, cognitive, and behavioral activity of a child, as an intrinsic learner in informal settings, and on the software design challenge as to whether we can design systems that support a child's ability to independently and intrinsically learn, explore, discover, and inquire with a high degree of emotional satisfaction, at all. How or why is a child motivated to learn about the world? What sparks interest? What sustains it, and can we, if we know, use that information to intentionally design systems that are the child's tool for learning? The best real-world example of sustained, enjoyable learning found was a field trip to a local wildflower reserve, Trillium Trail, where there were many examples of *Teachable Moments* (Bentley, 1995). Here was a real-world example from which to start my study, to try to understand, and to possibly simulate. The second set of problems center on how to design and engineer a system and user interface that could simulate such a rich and dynamic experience with the same type of learning results observed in the real field trip.

We are concerned with the traditional HCI parameters of usability and efficiency; however, we wanted to go beyond keystrokes, and link the overall system usability to the goals of the child in terms of learning, activity in-situ, time voluntarily invested, emotional and subjective reactions, and acts of creation. Thus, the first part to solving this problem was to take a user-centered design approach to human-computer interaction (HCI), where the larger goals of the child involved in intrinsic learning were explored in the pilot study as discussed in Chapter 7. This is a detailed ethnographic analysis of the child, the activity, the context, the tools, teacher, peers, and all activity as it relates to the child-environment interaction. The ethnographic study of the pilot allowed for the building of a realistic simulation for the main empirical study.

Simulated Ecological Environments for Education (SEEE) is introduced as a new type of simulation to support children in their intrinsic desire to learn, engineered as a system that can be used to isolate design factors for research. The technical goal was to build a realistic simulation of the field trip. The simulation had to represent reality, and thus it was based on data. A scientific visualization of the real place, with statistically accurate plant population data densities and terrain data, was a critical success factor, and makes this system different from others. The content in the user interface also had to be accurate. So the educational curriculum from the Audubon Society of Western Pennsylvania fourth-grade ecology lesson plan, *Natural Communities*, was used. Furthermore, the interaction had to be realistic and useful, and so the activity of the real-world field trip supplied from the pilot study was used to create the Virtual Trillium Trail. As the Virtual Trillium Trail is a software artifact, it was intentionally designed and engineered to allow for a technical, and thus a statistical, isolation, scaling and the framing of the factors for empirical investigation. This is required for a tight, empirical, planned orthogonal contrast with exceptionally high internal validity. The main empirical research goal was to decompose the experience into the main system design parameters for the virtual environment, to measure their impacts on learning, in-situ activity such as exploration and inquiry, and to attend to the subjective, emotional reactions to the system.

Visual Fidelity as a main factor to test became an obvious choice, as the current state of educational technology is rather low-fidelity and cartoonish in quality. The technical trend in computer graphic interaction is also towards a real-time, photo-realistic model, as is observed in the current market state of “serious games” technology. The obvious question is whether or not the quality of the image makes any difference for learning. Thus, the first factor under investigation is *Visual Fidelity* and how much of an impact it has on learning, *in-situ* activity such as exploration and inquiry, time spent on the task, subjective attitudes, and emotional response. The obvious practical implication of this research is tied to the quality of educational software produced and offered to our children, in terms of visual fidelity and effectiveness. The research goal is to determine the impact of *Visual Fidelity* on learning, activity, and attitudes.

Navigational Freedom as the second main dimension was another obvious choice, as the current state in educational software navigation is programmer or instructor determined. Furthermore, the game technology or other virtual environment software development platforms could be leveraged to allow full navigational freedom and thus way-finding choice in movement, or user-selected navigation and movement. *Navigational Freedom* is investigated as a factor in learning, *in-situ* activity such as exploration and inquiry, time spent on the task, subjective attitudes, and emotional response. The obvious practical implication is linked to the quality of educational software produced and offered to our children. In terms of navigational freedom, the current state of the art is either linear, drill-and-practice, guided or scaffold. While there are many studies that have investigated the advantages of restricting the movement on both the physical navigation and the cognitive navigation through information, few have taken such a rigorous empirical approach with high internal validity to analyze the design factors and the conditions under which they may have an impact on overall performance and enjoyment. The research goal is to determine the impact of *Navigational Freedom* on learning, activity, and attitudes.

4.1. Overview of the Dissertation Studies Overview

Thus, there are two studies, one qualitative and the other quantitative, presented in this paper. The first qualitative design is an ethnographic study that is a comparison of a real science and ecology field trip, and a virtual field trip in the SEEE. The result of the first study is an in-depth, qualitative report on the experience, structured to compare the two experiences, real and virtual, which is the first of its kind. The second study is an empirical investigation into the impact of each of the two primary design factors, *Visual Fidelity* and *Navigational Freedom*, also the first of its kind. The statistical analysis of the second study is a planned orthogonal study, a 2x2 ANOVA. The results clearly show the impact of the factors as design options in the user interface for virtual environments for learning.

4.2. The Pilot Study: An Ethnographic Analysis for UCD

The pilot study is an ethnographic comparison study of the real-world field trip to The Trillium Trail Wildflower Reserve and a virtual environment field trip, The Virtual Trillium Trail, is considered to be one of the best practices in User-Centered Design (UCD). The detailed observation and recording of the activity in-situ, with respect to the larger user goals of intrinsic learning, are the main deliverables of such ethnographic work, and used as the foundation for the next phase of system design. The students completed an in-depth experience with both of the two environments, a post-experience interview, attitudinal survey, and a microworld activity. One goal is to capture the user activity in such settings to deepen understanding and as a way to generate new insights. A secondary goal is to capture enough information about the child's experience to give a meaningful interpretation of the relative impact of the order of real-virtual and virtual-real experiences, as the order may indeed have an overall impact on the learning experience. The last goal is to evoke voluntary and spontaneous reflection on the experiences. A critical technique is the videotape activity, which captures the dialogue and gestures of the teacher and the students in-situ. The last activity was the creation of a microworld. How the child behaves in the context of the real or virtual field trips and the types of events that trigger responses will be of interest.

4.3. The Main Study: An Empirical Analysis of Salience Fidelity

4.3.1 Planed Orthogonal Contrast in System and Statistics

The second study is an empirical and quantitative investigation into the HCI design parameters of a SEEE on the dimensions of visual fidelity and navigational freedom. The structure is a planned orthogonal contrast, with a statistical 2x2 ANOVA design, and examines in-situ task activity of exploration, inquiry, learning, emotional response / expression, and acts of creation in a carefully controlled empirical study. We want to know the degree of impact these factors, visual fidelity and navigational freedom, have on the outcomes of interest.

The SEEE is intentionally designed to support investigation into two main HCI design factors relevant to simulations and virtual environments for learning. Additionally, the software system affords high internal statistical validity supportive of planned orthogonal contrasts and ANOVA statistical designs. The SEEE software combined with the statistical design allows for high degrees of confidence, minimized variance, and is thus ideal for investigations into independent factors and interaction effects among factors. It also provides an excellent baseline for the modeling and fitting of the estimators / betas for regression equations. Of the many HCI design factors we could investigate, we intentionally selected the two high-level design factors commonly used in virtual environments that of the quality of the image and the amount of individual freedom permitted in the space for navigation and exploration.

4.3.2 Visual Dimension

The virtual environment, as a software construct, may be intentionally varied at the software designer's will. For example, low visual fidelity may be represented by cartoons, and high visual fidelity, by photorealistic movies, both instantiations are under the designer's control. Thus, there exists a range of visual fidelity that may or may not have an impact on desirable outcomes in educational software. For the main study the visual dimension was manipulated easily. The same 3D model of the Virtual Trillium Trail was textured with bitmapped images representative of the low visual fidelity, "*cartoon level,*" or high visual fidelity, "*photorealistic level.*"

While the software and hardware advances have made photorealistic representation in 3D computer graphics and real-time interaction (CGI) easily achievable (Crytec, 2006), the open question remains, as to what impact, if any, visual fidelity can have on a learning experience in virtual environments. There are many educational and learning software applications that use a low-fidelity, cartoon-genre image quality such as those produced by the high quality Discovery publisher (see Appendix B and C). Furthermore, because the low visual fidelity quality image is faster to render, requires less memory or space on a network, it is used especially for small, portable devices that require lower computation demand. Thus, the one main factor selected in the virtual environment to examine is that of the visual fidelity—from a low-fidelity to a high-fidelity 3D CGI style.

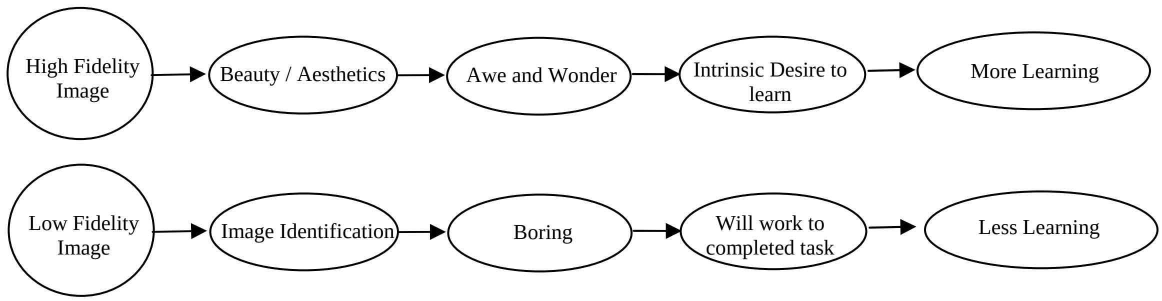


Figure 7: The top causal chain is the theoretical representation of the child's response to a SEEE with high-fidelity images. The bottom causal chain is the theoretical representation of a child's response to a SEEE with low-fidelity images.

4.3.3 Navigational Dimension

The second critical dimension chosen for this study is in the user interface dimension. The main categories of any user interface system consist of search, navigation, augmentation, and annotation. One of the unique user interface design features in a SEEE is the type of navigation permitted to the user. As in any virtual environment, there exist infinite degrees of freedom in the navigational choice for the user. This is the factor assumed to have the greatest impact on individual, intrinsic exploration and, as such, is the one chosen for investigation. ***The assumption is that unlimited, freedom of choice of navigation, in direction, pace, and duration of exploration, will increase the number of inquires, increase the distance traveled, increase the time in the system, and will also enhance exo-centric and contextual knowledge and understanding, as well as understanding of cause-and-effect and form-and-function relationships through direct observation, as well as emotional engagement and episodic memory.***

The low end of navigational freedom can be created in the virtual environment by simply restricting the routes to the path. In this way, the subjects may travel forward, backwards, and inquire about objects in view, but cannot go off the trail. Under this condition, the navigation is similar to the real-world field trip, where the children must stay on the path.

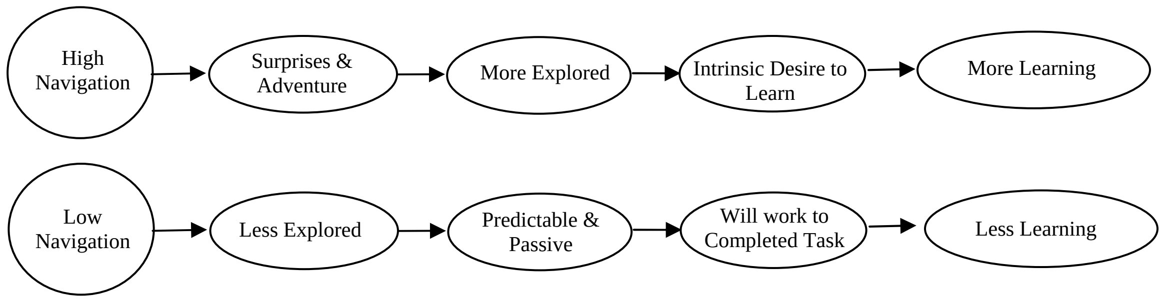


Figure 8: The top causal chain is the theoretical representation of the child's response to a SEEE with high navigational freedom. The bottom causal chain is the theoretical representation of a child's response to a SEEE with low navigational freedom.

4.3.4 2x2 ANOVA Design

Since this is ***a planned orthogonal contrast experiment (POC) used to increase the power***, a 2x2 ANOVA design tests the results for independence of the SEEE variables. The ideal study and research design would produce properties of estimators of parameters that are unbiased, efficient, and consistent, with distributions that are normally distributed and variances approaching zero. A 2x2 ANOVA is the statistical design for the main study. Each factor, *Visual Fidelity* and *Navigational Freedom*, had two levels. *Visual Fidelity* was represented by Low Fidelity (LF) and High Fidelity (HF) system conditions. *Navigational Freedom* was represented by the low navigational freedom (LN) and the high navigational freedom (HN) system conditions

The following conditions were tested in the experiment:

1) SEEE *High Visual Fidelity* and *High Navigational Freedom* (HFHN)
2) SEEE *High Visual Fidelity* and *Low Navigational Freedom* (HFLN)
3) SEEE *Low Visual Fidelity* and *High Navigational Freedom* (LFHN)
4) SEEE *Low Visual Fidelity* and *Low Navigational Freedom* (LFLN)

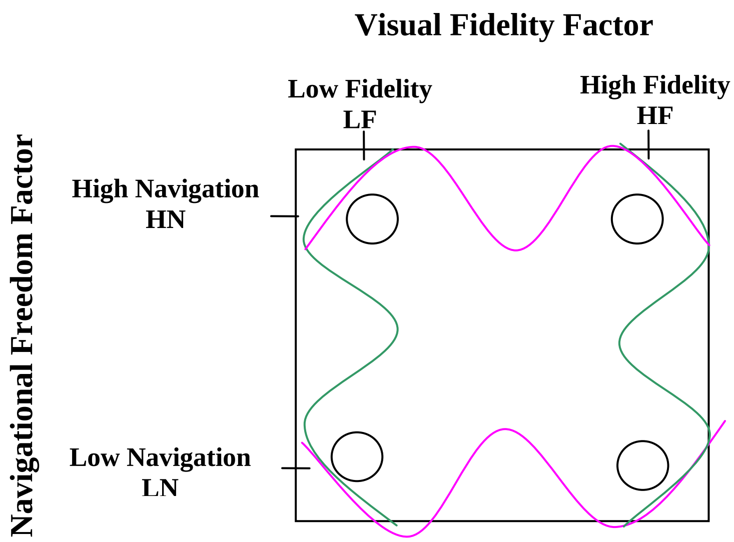


Figure 9: Research questions represented graphically in two dimensions.

5. A SEEE System as the Virtual Trillium Trail

A significant methodological feature of this study is discussed in here, for the planned orthogonal statistical design demanded a system that would allow the isolation, measurement, and manipulation of the factors. The Virtual Trillium Trail is also the first model for virtual environment data simulation and a very powerful learning environment based on reality and data—not fantasy. Descriptions of the software, approach, and curriculum are also provided in this chapter.

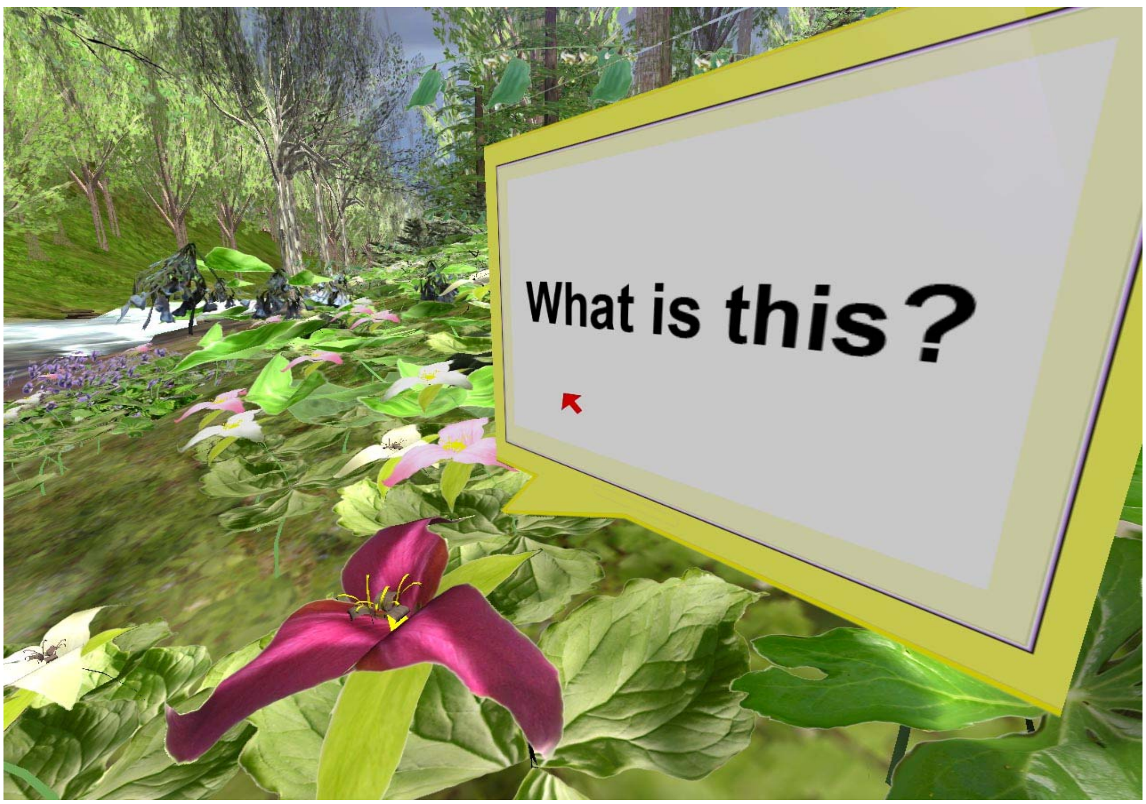


Figure 10: SEEE System as the Virtual Trillium Trail

5.1. Overview

The real-world observation of the activity of elementary school children learning about science and ecology on a field trip to a local park was the basis for the development of the simulation. The Virtual Trillium Trail is a SEEE system for research and a visualization of data of the real Trillium Trail, a wildflower reserve located outside of Pittsburgh, Pennsylvania. The system is geospatial and based on scientific data (Kalisz, 1996-2006), as well as on the fourth-grade curriculum *Natural Communities* (Audubon, 2006). It also allows for high internal validity by allowing the research scientist in HCI to select levels of the factors in the UI environment, which is ideal for the planned orthogonal contrasts and the resulting statistical tests.

5.2. Technology Platform and Development Tools of a SEEE

Figure 11: An example of a 3D terrain generated and the addition of 3D plant species models added to the virtual ecology. Maria C.R. Harrington © 2006

The SEEE visualizes approximately one square mile of local ecology that was generated from terrain contour data in Digital Elevation Model (DEM) format and locally gathered textures from over 1,500 on-site photographs. The ecological regions are based on ten years' worth of scientific biological plot study data (Kalisz, 1996-2006). The SEEE is populated with semi-automatically-created 3D computer graphic objects of indigenous plants (4,000 objects of 500-1500 polygons each), in a model that totals to approximately 10 million polygons. It is a statistical equivalent to the real place, and thus ideal for research and testing. The SEEE is one of the few, if not the only, existing virtual environments of a real place of nature designed for HCI and educational research in a real-time, interactive software environment. The model was constructed in UnReal, using the editor (UnReal Technology, 2008) and other third party tools. The application runs on a Dell XPS Gen 2 and requires a high-end graphics card. Currently, there are only 36 species of the 102 to be modeled. The plants are available for interaction and fact inquiry.

The simulation of the natural environment is highly realistic, while not yet driven by ecological agents for dynamics; it is statistically identical to the ecological environment as it would exist in a moment of time without human or excessive deer populations. Furthermore, the simulation provides a near-realistic experience for the user. In it, the child can explore, navigate, inquire, learn, and create. It is unique for learning as it is based on reality and facts; it is contextual, has events, is multi-modal (visual and sound), and is completely under the users' navigational control, without points, money, or other external motivators.

5.3. Research Importance of a Simulation and Scientific Visualization

This research is different from previous projects in several important ways. First, it is based on scientific, accurate, recent, relevant, and local data derived from plot studies (Kalisz, 1996-2006). Second, the visualization is a simulation deployed in an egocentric or first-person game engine, for a personal and close-up investigation of the real data embedded in the visualization. Third, the research seeks to augment and overlay the simulation with UI devices, tools, and techniques to facilitate scientific exploration, inquiry, investigation, recording, collaborating, and creative activities. Fourth, it is a tool designed with the unique needs, goals, and constraints of children as software users in mind, supporting their actions as junior naturalists, scientists, and field biologists. It is similar to the first-person role playing games, but when used with the real field trip or a naturalist guide as teacher has a real scientific mentorship element and novice-to-expert scaffolding activities.

A critical point in this research is that the virtual reality is based on and modeled from a real place, so as to minimize any programmer's or designer's unintentional introduction of misconceptions. "***What you see is what it is,***" a "**WYS-I-WII.**" Basing on reality is a critical design factor for success in such systems, as the goal is to create an authentic simulation of reality.

When is it acceptable for the software designer or the educator to deviate into fantasy?

The Virtual Trillium Trail is not like other "virtual field trips" of the past, some of which were "*What you see is* not *what it is,*" as many of those systems, which were based on 2D photographs and deployed in hyper-media systems, limit the student navigation to the programmer-selected route or path, or to cartoon-like Flash-based systems that lack all visual detail found in the photographs or video. Other "virtual field trips" deployed in Desktop Virtual Reality Environments, such as Quest Atlantis (Barab, et al., 2007) or River City, a type of multi-user virtual environment, MUVEs (Dede, et al., 2005) were constructed to reflect fantasy or fictitious environments, and therefore are theoretically capable of introducing unintentional misconceptions.

The Virtual Trillium Trail is very different from those other virtual environments in that it is not a 2D hyper-media, or Flash based, system; rather, it is a true desktop virtual environment and a data-generated simulation of reality, affording high photo-realistic visual fidelity and complete user freedom of navigation, exploration, and movement, which is so essential for independent student exploration and inquiry.

The three critical differences are that The Virtual Trillium Trail is: 1) a 3D computer graphic data-based simulation, 2) deployed with common game-engine technology so to allow complete freedom of movement and selection of objects, and 3) with graphics that are high-fidelity, photorealistic approximations of the real location. Thus, Virtual Trillium Trail is the first ever high-fidelity visualization of a real location used for real field trips.

5.4. Future Work on the System

Potentially, a new technical distribution platform could efficiently and automatically leverage and reuse scientists' data from local plot studies around the world into automatically built visualizations of local ecologies, which then could be integrated into local classroom science learning activities and be freely accessible over the Internet for virtual field trip experiences. The realization could be multi-cultural, collaborative, virtual science lessons with novice children and expert biologists.

By expanding the development process required to generate virtual ecologies from real-world geospatial data, satellite images, and ground-level plant species plot data for statistically accurate dispersion patterns of the 3D computer graphic plant models based upon ecological context and empirical data, it is hoped that the SEEE contributes to the body of knowledge that will empower current and future scientists and artists. While not landmark-specific, this technique has the future potential to allow egocentric and ecologically-correct environments to be constructed in a semi-automatic way, with data driven from the leveraged field work of expert Biologists conducting their science.

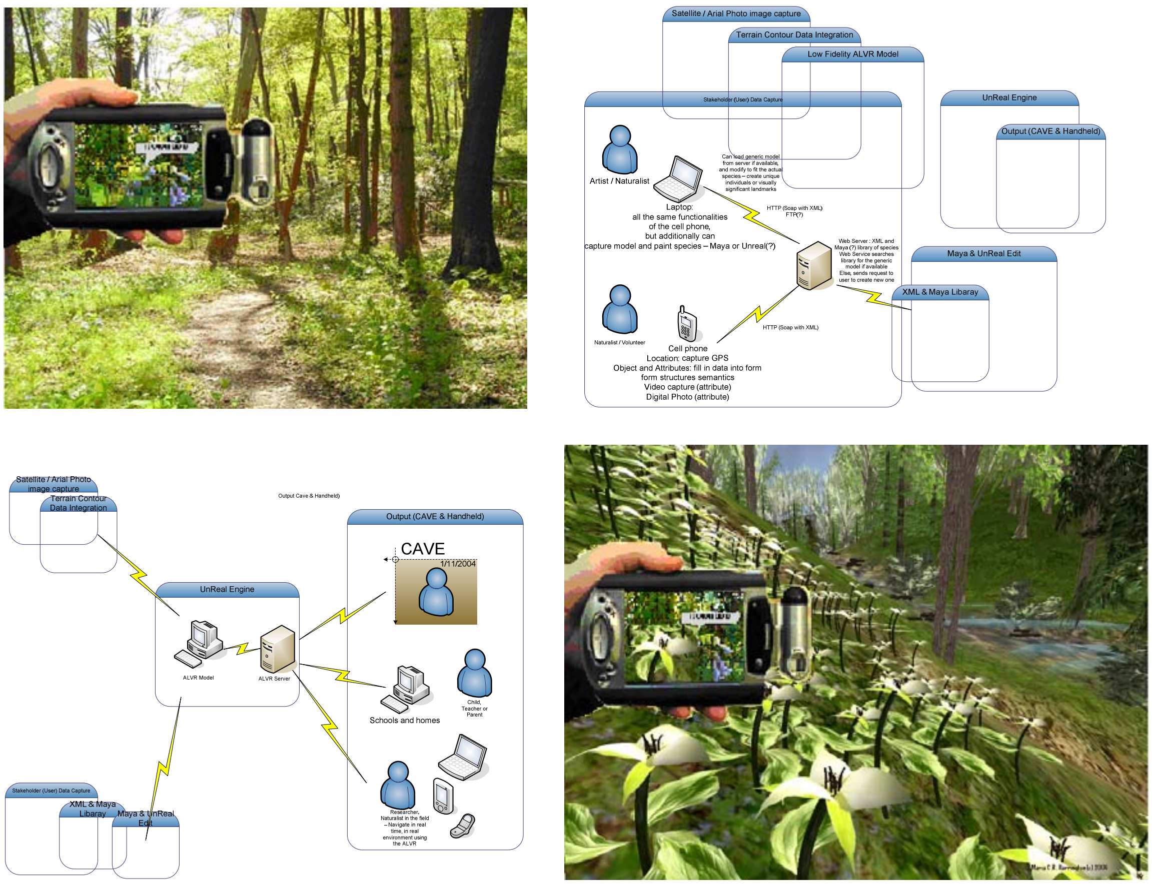


Figure 12: An overview of future system architecture for user data capture – biologists and naturalists and system output in homes, schools and science centers or museums over the internet. Maria C.R. Harrington © 2006

5.5. Curriculum

The educational content embodied in the system was based on the Audubon Society of Western Pennsylvania's *Natural Communities* curriculum for the fourth grade (Audubon, 2005). The facts, concepts, and values will be ***held constant at the highest expert level across all experimental studies and conditions.*** The fact ontology has two parts, the declarative and the procedural knowledge that is embodied in the system. The content can be defined in relative terms and expressed on a continuum. However, that continuum will not be explored here, although it could be expressed as a range from novice to expert, or the child to the guide naturalist up to the biologist scientist. It also represents the rich future research opportunity to integrate an intelligent tutor with this ontology and to explore the other aspects of moving a child from a novice ontology to an expert ontology.

The Audubon content was part of the academic curriculum at the local public school. The school's curriculum was compared, with the help of a fourth-grade public school teacher and science expert, to the Audubon content, and it was determined that there was 100% coverage, with the Audubon curriculum going deeper than the school's material on some concepts. Further analysis was conducted with respect to the Commonwealth of Pennsylvania Ecology standards (Pennsylvania Department of Education, 2002), and it was concluded that the state standards were a subset of the Audubon's and the school's curriculum. A detailed analysis compared the Trillium Trail plot study data to the 3D system simulation to the curriculum. As only 35% of the plant species were modeled, there was a concern that there would not be enough material for an accurate experience. The teacher's expectations of the real field trip were established as: 1) the students would learn two new plants and increased observational sensitivity to the parts of the plants, adaptations, and salient features; and 2) they would gain a deeper understanding of watersheds and forest communities, 3) biotic and abiotic interactions, 4) Northeastern forests and the layers of the forest, 5) pollination in action, 6) photosynthesis in action, and 7) deeper understanding of the web-of-life, ecosystems, and the interconnecting dynamics found on site. The system had 40 plants selectable (36 plant types) tagged with facts and over 75 concepts available (14 concept types) available for direct interaction and inquiry. We determined that the virtual field trip was adequate to support the content for teaching such material.

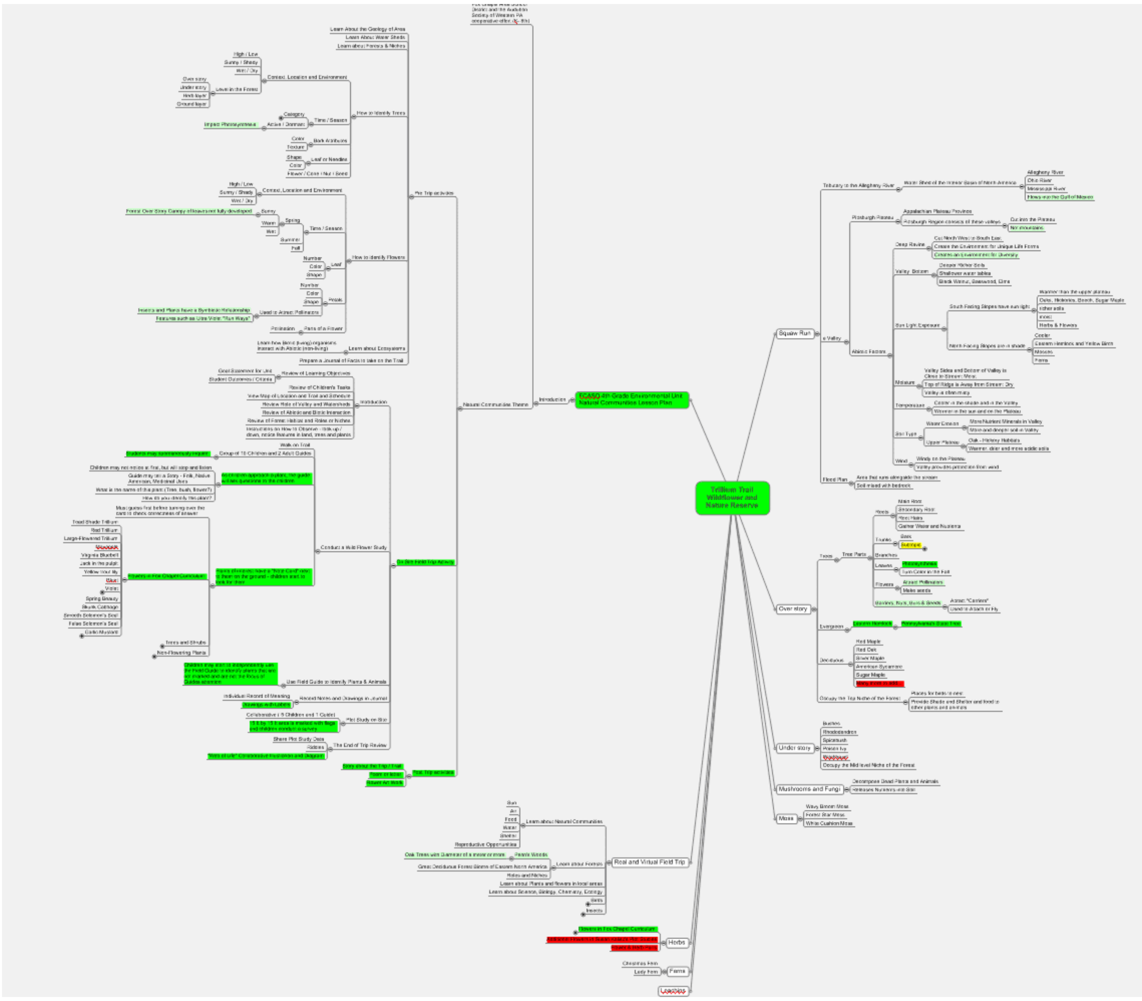


Figure 13: The Trillium Trail fact, concept, value ontology combined with the Natural Communities Curriculum as ontology

For this research, it will only be necessary to define the highest fidelity representation of the object. ***This ontology can be thought of as 100% of the information in the lesson unit,*** with an ontology of over 300 nodes. The following is a sample from the ***Natural Communities Lesson Plan. However, there is no strategy to guide access to the knowledge, as there are in intelligent tutoring systems. This is an area for future research.***

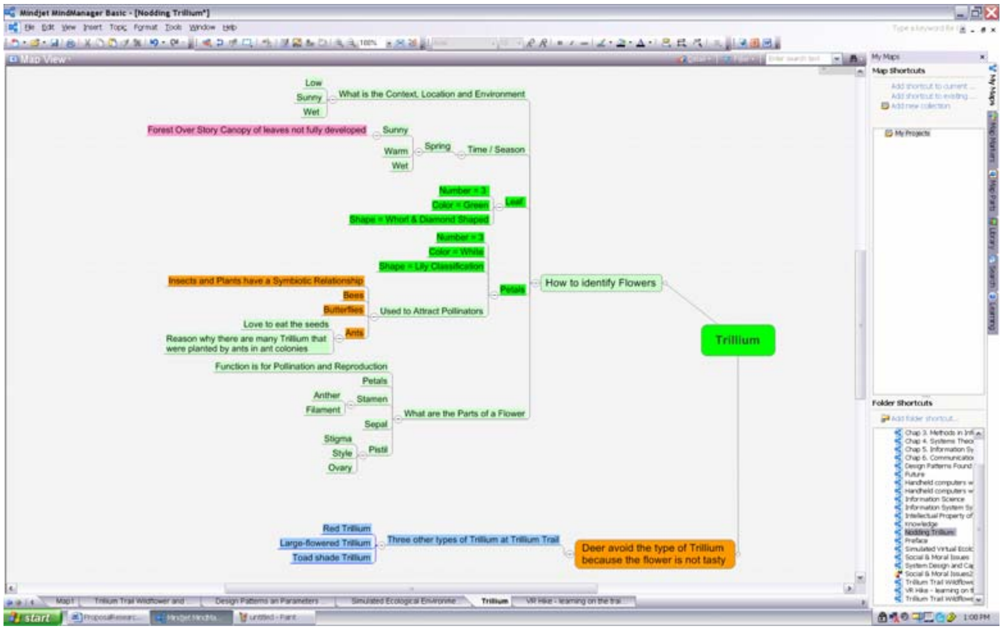


Figure 14: A close up view of the Trillium Trail ontology. This is also part of the User Interface design in a SEEE

Figure 15: A sub-set of the Trillium Trail ontology for the Natural Communities Curriculum

In the course of gathering content for the *Natural Communities* lesson unit, data for the Trillium Trail ontology was graciously provided by the Beechwood Environmental Educators Gabi Hughes and Scott Detwiler; teachers from an elementary school; plot study data from Dr. Kalisz and students from her lab in the Biology Department of the University of Pittsburgh (Kalisz, 1996-2006); and online from the Pennsylvania State Academic Standards for Science and Technology and Environment and Ecology (22 Pa. Code, Ch 4, January 5, 2002). Each set of data was different. Some of it overlapped;

some of it did not. Thus, data sets were combined to represent the maximum set of facts in this domain and ontology for this lesson plan of Trillium Trail.

5.6. User Interface

Figure 16: A screen capture from the Simulated Ecological Environment for Education of Trillium Trail and an example of the context, object, and interactive fact cards UI available for user exploration

The user interface (UI) was iteratively developed with the students, incorporating their feedback from the pilot study. All four conditions of the main study had the same user interface (UI) elements, which were identical. The mouse and / or the touch pad was used to pan the view up, down, left, or right. The keyboard arrow keys were used to move forward, backward, left, or right. All of the system conditions were identical in location, placement, look and feel, and interaction behavior of the UI. The virtual objects, such as trees, bushes and flowers, had dynamic UI augmentation "fact cards" positioned next to them much like a "tool tip" to facilitate user-controlled deep factual inquiry on the object which resulted in the *Fact Inquiry* count for the UI. The system used sound and dynamic image sprites to draw the user's attention to audio content in context-sensitive locations. These were used much as the *Teachable Moments* guide facilitated stories and concepts in the real field trip. The fact cards and the sprites provided *Salient Events* and thus opportunities to stop and inquire, and to read, or learn by listening. Both result in *Salient Event* counts in the UI log. The UI was identical in all four conditions. These *Salient Events* are shown to be very important for learning.

UI Factors:

1) Fact Cards: Users would initiate inquiry by placing the mouse cursor arrow on top of the target fact card and then using the keyboard space bar. The UI would flip the cards, thus navigating down through the facts in a linear fashion. The fact cards were organized in the same way for all objects. The first card asked the question, “What is this?” Then, pending the user’s selection, the card would flip and tell the user the name of the object. The next card in the stack would ask the question, “How do you identify it?” Then, pending the user’s selection, the card would flip and tell the user how to identify it. The user has free choice when to inquire, how long and how far down the fact hierarchy, to repeat or not, and when to leave.
2) Sprites: Passive audio delivery of information was also implemented in all four systems. These audio files were located in visually dynamic sprites – animated icon that appeared to glitter. The user was able to freely walk up to and listen, or to walk by and ignore.
3) Salient Events: An intentional focus on information for the purpose to inquire and learn. The act of a child first perceiving a card or a sprite, and then walking over to it, and then stopping at it, and either reading the cards or listening to the recording.
4) No use of a “You Are Here Map” for context in all systems, although it was needed to facilitate exo-centric way-finding. The users in the High Fidelity condition would fly up above the terrain to obtain a bird’s eye view. It is a desirable feature and is expected to be added into a future system.
5) No search will be implemented for the experiment. However, this is a desirable feature for most systems and is expected to be added into a future system.
6) No additional soft UI tools will be implemented, such as magnifying glass, compass, binoculars, or microscopes. However, these are highly beneficial, have been documented as tools users rely on in the field, and are expected to be added into a future system.

7) No avatars, insects, birds, animals, fish, or any other agent based or artificial life will be available. However, these are viewed as beneficial and are expected to be added into a future system.
8) No use of scientific visualization or graphs, charts, or other visual displays of data, however desirable. The technical limitations in the current platform preclude advancement.
9) No online journal, online sketchpad, or any other user annotation functionality. The current test allows the user to record information on paper, yet it may be desirable to integrate such tools into a future system.
10) No social interaction: This one was intentionally designed for non-collaborative work. However, the technology platform is fully capable of supporting collaborative experiments.

5.7. Activity Data Capture Process

The process of logging events was manual, entailing field notes as well as a post-study analysis of all videotapes. This was required, as any automatic process was biased upwards, since students would hold down the space bar and flip through the fact cards without reading, or walk through a sprite without listening. Only students observed reading the fact cards, or stopping to actively listen to the sprites had those events recorded as true events. There were also times when a student passed through a sprite without listening to it, so only events which the student actually stopped for more than one second were counted as true events. Future automatic logging of student activity over time must build in rules with time requirements and procedural changes that will require the students to read aloud. The video will be used in future studies, as the approach, while more operationally difficult, proved critical for insights into the data. This type of highly detailed observation can only be derived through ethnographic observations, but rewards with valuable insights.

5.8. Relating the Planed Orthogonal System Design to the SEEE Tripartite Model for Research

In the past, internal validity in research on user interfaces that crossed multi-dimensional space was difficult, if not impossible, to justify, as it is impossible to control for differences when comparing radically separate user interfaces, such as a book to a hyper-media system to a virtual reality system. The SEEE Tripartite Model creates a framework on which factors can be measured, scaled, controlled, and manipulated on the same system. There are not four separate systems; there is only one system, with the factors set to different levels. This tight empirical control allows the researcher to hold some factors constant, while manipulating and measuring outcomes in a controlled, systematic, and empirical way.

6. Software Designed and Engineered to Support Planned Orthogonal Contrast Research Aims

This chapter describes in detail how the salience for the system was intentionally designed and engineered to make the statistical analysis viable and to build the required foundation for the regression models. Internal validity in both the system and the statistics was carefully ensured and built, for a planned orthogonal contrast.

6.1. Continuums of Salience

The SEEE research questions demand a system architecture that will support measurement, modification, and recordings of changes to image fidelity, salience, context, and navigation, as these variables impact the quality of the user interface, the virtual environments, and user activity. These two main factors, *High Visual Fidelity* (proxy for "beauty") and *High Navigational Freedom* (proxy for "free choice"), are examined in detail as possible causal UI and VE factors in individual, intrinsic learning in informal settings.

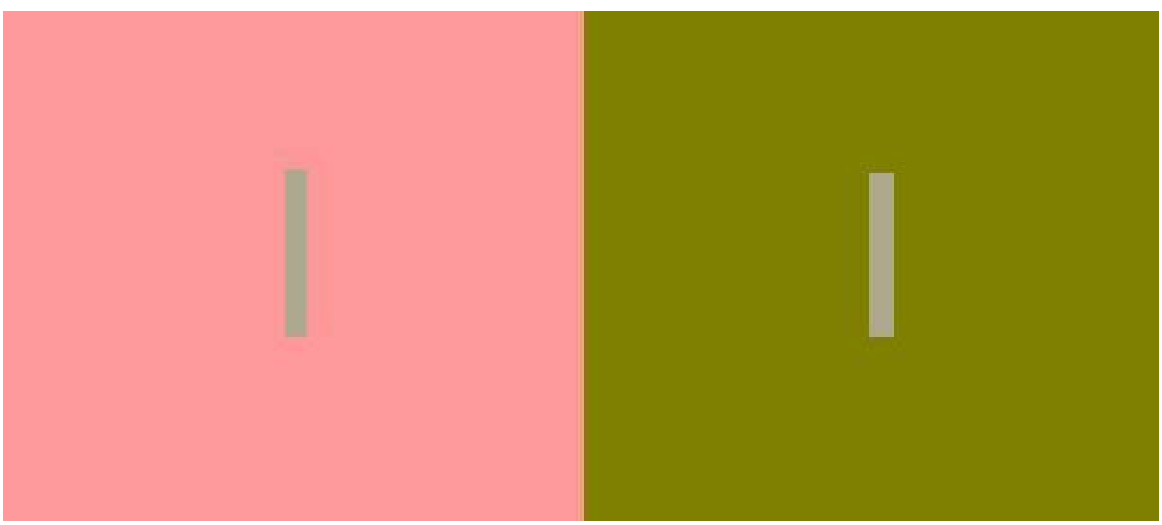
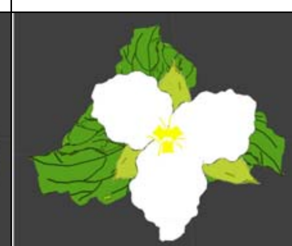
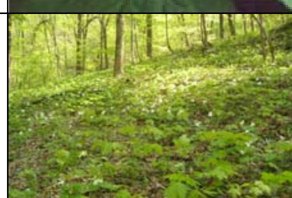
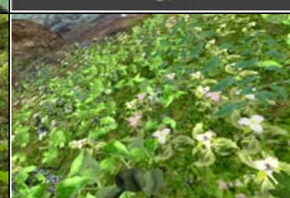
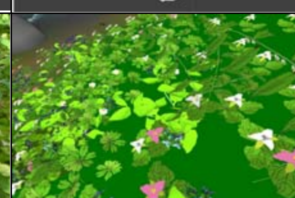


Figure 17: An example of a color study. The color of the center objects are the same.SEEE Visual Fidelity Continuum

These variables may be just like the variables of color and shape in Joseph Alber's color interaction studies, where an object's color appears to change depending on relative colors, relative size, and context of the object's figure-ground relationships as they are visually expressed in positive-negative space relationships. So too, these variables in the UI appear to be mutable. Nevertheless, once the appropriate values are identified and measured, and the appropriate scales defined, then, even when used jointly, they can become quantifiable and predictable.

6.2. SEEE Visual Fidelity Continuum Matrix

Table 1. SEEE Visual Fidelity Continuum Matrix

		Visual Fidelity Category		
Context Category		**Real (Standard)**	**High Fidelity**	**Low Fidelity**
	Object (Flower)			
	Ground (Hillside)			
	Ecological Environment (Trillium Trail)			

Since visual information is perceived on a field trip in context and is also presented to children in lower-fidelity media, such as black-and-white images and cartoon-like CBT systems, it is important to first define the parameters of visual information salience for the SEEE. Based upon the context in which visual information is presented, the user can easily misinterpret visual information. Table 1. presents the images in a continuum of visual fidelity and context, where the real image represents the standard and most accurate, or maximum visual fidelity, and the cartoon image represents an abstracted and lower visual fidelity image. An example of high-fidelity images was taken from the virtual environment. One should note that the SEEE constructed images can be created to fall anywhere between the two extremes. Furthermore, image histogram analysis could be used for exact measurements.

6.3. A Priori SEEE Salience Formulas

One of the many advantages of scaled values is the ability to empirically test the closeness of match the empirical results to those predicted by the scaled values of the variables.

Equation 1. A Priori Visual Fidelity Equation

VE = IS + PF + CONTEXT, where:

PF= CP+NP+LS+NL+CL+S+C+SH+T+SHD

CONTEXT= VC+SH+T+SHD

Given:

IS= Image size

PF= Plant Features:

- **CP**= Color of Petals
- **NP**= Number of Petals
- **LS**= Leaf shape
- **NL**= Number of Leaves
- **CL**= Color of Leaves
- **S**= Stem
- **C**= Context
- **SH**= Shading
- **T**= Texture
- **SHD**= Shadow

Context

- V**C**= Visual Context
- **SH**= Shading
- **T**= Texture
- **SHD**= Shadow

Equation 2. A Priori Navigational Freedom Equation

UI = NOD + NDOF+CONTEXT+ ERG+ E, where:

NDOF = FH+NO+PO+JTO +PD+NPD+TT

CONTEXT= IC+YAHM

ERG= RGUD+RGRLR+RGFOVS+RGNSFOV

Given:

NOD= Number of Object Nodes: plants (100%) = (10)

NDOF=Navigational Degrees of Freedom Features:

- **FH**=Down the object fact Hierarchy: (100%) Possible to explore all object's facts = (10)
- **NO**=Select to go to the next object: (10)
- **PO**=Select to go back to the previous object (10)
- **JTO**=Select to jump to any of the other objects (10)
- **PD**=User can choose programmer allowed direction (0) "must stay on trail"
- **NPD**=User can choose non-programmer allowed direction (10) "Off-trail"
- **TT**= Time travel forward or back (10)

Context

IC=Passive inquiry on context: (10). Constant variable, limited passive voice. ex. "Do you notice if it is moist or dry?"

YAHM=Show a You Are Here Map for context. Facilitate exo-centric wayfinding. (0)

ERG=Ecological Redundancy Gain (may be part of Context)

RGUD=Redundancy gains of up/down (10)

RGRLR= Redundancy gains of left/right (10)

RGFOVS= Redundancy gains of new Frame of View and Same Scale: Look up/down? (10)

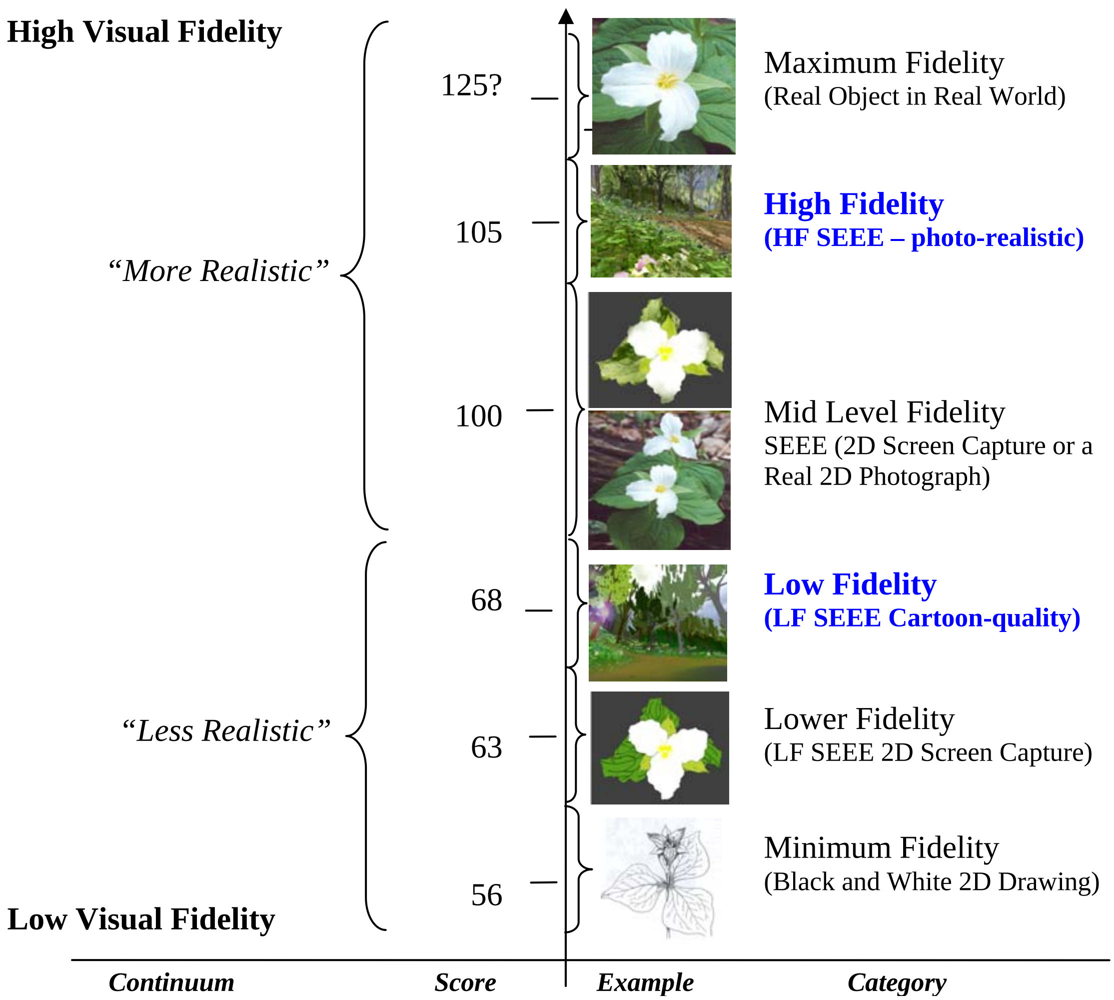
RGNSFOV= Redundancy gains of New Scale and Frame of View: Fly Mode of Zoom-Out (bird) or Shrink Mode or Zoom-In (bee) or Magnifying glass.(10)

E=Exit at any time (10)

6.4. SEEE Visual Fidelity Scale

Visual fidelity may be expressed on a scale, an example of which would rank and order images from a low value to a high value of visual fidelity. A simple black and white 2D image may be considered as an example of low fidelity, with a score of 56. Alternatively, the real-world 3D object may be considered as an example of high fidelity, with a score of 105. The range for each attribute was (0-10). The total score represents its rank and order on the continuum. For this research, it will be necessary to choose ***two points*** that are representative of a ***low fidelity*** (score of 68) and a ***high fidelity*** (score of 105) as visual representations of the objects used for comparison.

Graph 1. SEEE Visual Fidelity Scale



Example 1 : Lowest fidelity 2D black and white (salience score of 56).

Consider the following example of a 2D black and white image of a Trillium from the an educational unit booklet.

Figure 18: An example of a 2D black and white image

Notice the visual attributes:

IS= Image size: 5 inches (5)

PF= Plant Features:

- **CP**= Color of Petals: (5) white with some texture
- **NP**= Number of Petals: three (10)
- **LS**= Leaf shape: Whorl (10)
- **NL**= Number of Leaves: three (10) with some texture
- **CL**= Color of Leaves: (0)
- **S**= Stem: straight and smooth (10)
- **C**= Context: none (0)
- **SH**= Shading: minimal (3)
- **T**= Texture: minimal (3)
- **SHD**= Shadow: none (0)

Example 2: Low-fidelity 2D color (RGB) (salience score of 63).

Consider the following example of a 2D color image of a Trillium, as one might expect in current state-of-the-art, computer-based training systems. The image resembles a **cartoon image,** as it lacks textural detail.

Figure 19: An example of a low-fidelity 2D color image.

Notice the visual attributes:

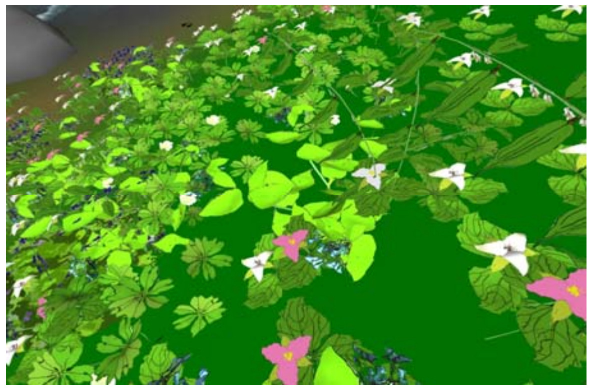
IS = Image size: 5 inches (5)

PF = Plant Features:

- **CP** = Color of Petals: (5) white, with out texture or variation
- **NP** = Number of Petals: three (10)
- **LS** = Leaf shape: Whorl (10)
- **NL** = Leaves: three (10)
- **CL** = Color of Leaves: (5) Green, with out texture or variation
- **S** = Stem: straight and smooth (10)
- **C** = Context: some (5)
- **SH** = Shading: none (0)
- **T** = Texture: minimal (3)
- **SHD** = Shadow: some (0)

Example 3: Lower fidelity virtual trillium in 3D (salience score of 68).

Consider the following example of a 3D color image of a virtual Trillium. The score is a bit higher due to the additional information provided by the context.

20: An example of a 3D color image.

Notice the visual attributes:

IS = Image size: 5 inches (5)

PF = Plant Features:

- **CP** = Color of Petals: (5) White with out much texture or variation
- **NP** = Number of Petals: three (10)
- **LS** = Leaf shape: Whorl (10)
- **NL** = Leaves: three (10)
- **CL** = Color of Leaves: (5) Green with out much texture or variation
- **S** = Stem: straight and smooth (10)
- **C** = Context: realistic (10)
- **SH** = Shading: some (3)
- **T** = Texture: minimal (0)
- **SHD** = Shadow: some (0)

Example 4: Higher fidelity (2D photograph (salience score of 100).

Consider the following two examples of 2D color images of a Trillium. The first is from my personal photo-library and the second is a screen capture from the HF SEEE.

Figure 21: An example of a 2D color photograph. The figure on the left is from the Audubon Society Field Guide, and the image on the right is screen capture from the SEEE of Trillium Trail.

Notice the visual attributes:

IS = Image size: 5 inches (5)

PF = Plant Features:

CP = Color of Petals: (10) White with texture or variation

NP = Number of Petals: three (10)

LS = Leaf shape: Whorl (10)

NL = Leaves: three (10)

CL = Color of Leaves: (10) Green with texture or variation

S = Stem: straight and smooth (10)

C = Context: some (5)

SH = Shading: realistic (10)

T = Texture: realistic (10)

SHD = Shadow: realistic (10)

Example 5: Highest fidelity virtual trillium (3D VE) (salience score of 105).

Consider the following example of a 3D color image of a virtual Trillium and the context of the Trillium on the virtual hillside.

Figure 22: An example of a 3D image screen capture from the SEEE. Note that in the SEEE it is a 3D model that can be viewed from multiple frames of reference and scale. Those context-sensitive features are not represented in the embedded image in this document.

Notice the visual attributes:

IS = Image size: 5 inches (5)

PF = Plant Features:

- **CP** = Color of Petals: (10) white with texture or variation
- **NP** = Number of Petals: three (10)
- **LS** = Leaf shape: whorl (10)
- **NL** = Leaves: three (10)
- **CL** = Color of Leaves: (10) green with texture or variation
- **S** = Stem: straight and smooth (10)
- **C** = Context: realistic (10)
- **SH** = Shading: realistic (10)
- **T** = Texture: realistic (10)
- **SHD** = Shadow: realistic (10)

Example 6: Real-world flower (salience score of unknown, estimated at 110).

Consider the following example of a 3D color image of a real Trillium from the real trail. This may be typical of the flowers that the children see in the real field trip.

Figure 23: An example of a photograph of a Trillium from Trillium Trail.

Notice the visual attributes:

IS = Image size: real size (6-24”, w. 1 ½”) (10)

PF = Plant Features:

- **CP** = Color of Petals: (10) white with texture or variation
- **NP** = Number of Petals: three (10)
- **LS** = Leaf shape: whorl (10)
- **NL** = Leaves: three (10)
- **CL** = Color of Leaves: (10) green with texture or variation
- **S** = Stem: straight and smooth (10)
- **C** = Context: realistic (10)
- **SH** = Shading: realistic (10)
- **T** = Texture: realistic (10)
- **SHD** = Shadow: realistic (10)

(Other features, such as fragrance, interaction with insects, animals, and humans not accounted for in this scale.)

Other signals that make it more salient would be smell and movement. Objects blow in the wind, or there may be the movement of pollinators near the petals. The translucence, reflections and refractions of light from surfaces, and other of these types of signals add unknown points to the salience score.

6.5. SEEE Navigational Freedom Continuum Matrix

The motivation behind the creation of the navigational freedom scale is to offer a range of navigational freedom in the experiment. Navigational freedom can be expressed on a scale. An ***example*** would rank and order many navigational interaction techniques found in UIs: from a low value to a high value. A simple linear wizard, with only one "Next" button available for selection, may be considered a form of low navigational freedom. Alternatively, a virtual environment with the ability to move in all directions, to pan, to zoom, and to get details on demand, may be considered an example of high navigational freedom. The highest level of navigational freedom is the virtual environment (VE) ***as it permits infinite paths and complete freedom of choice***, independent of programmer or designer intentions.

Notice that the navigational dimension is more complex than the visual fidelity scale. The visual scale was more discrete, with fewer and smaller overlaps of salience. Not so with the navigational dimension; this may be due to the designer or programmer's choice in the construction, since many UI design choices can influence the quality of the execution and thus influence the navigational freedom score. It may be possible to create an hypermedia system that is identical to the linear CBT types of systems – it is simply a matter of having the developer only code a strict linear path. That is a design choice and decision. However, one may also design and execute an hypermedia system that is superior to the real-world field trip, if executed in such a way that the software has more links, paths, and context than is available in the real world. One has to stay on the path in reality, but not so in the system. The system's route is designed, and can therefore be anything that the designer wants.

6.6. SEEE Navigational Freedom Scale

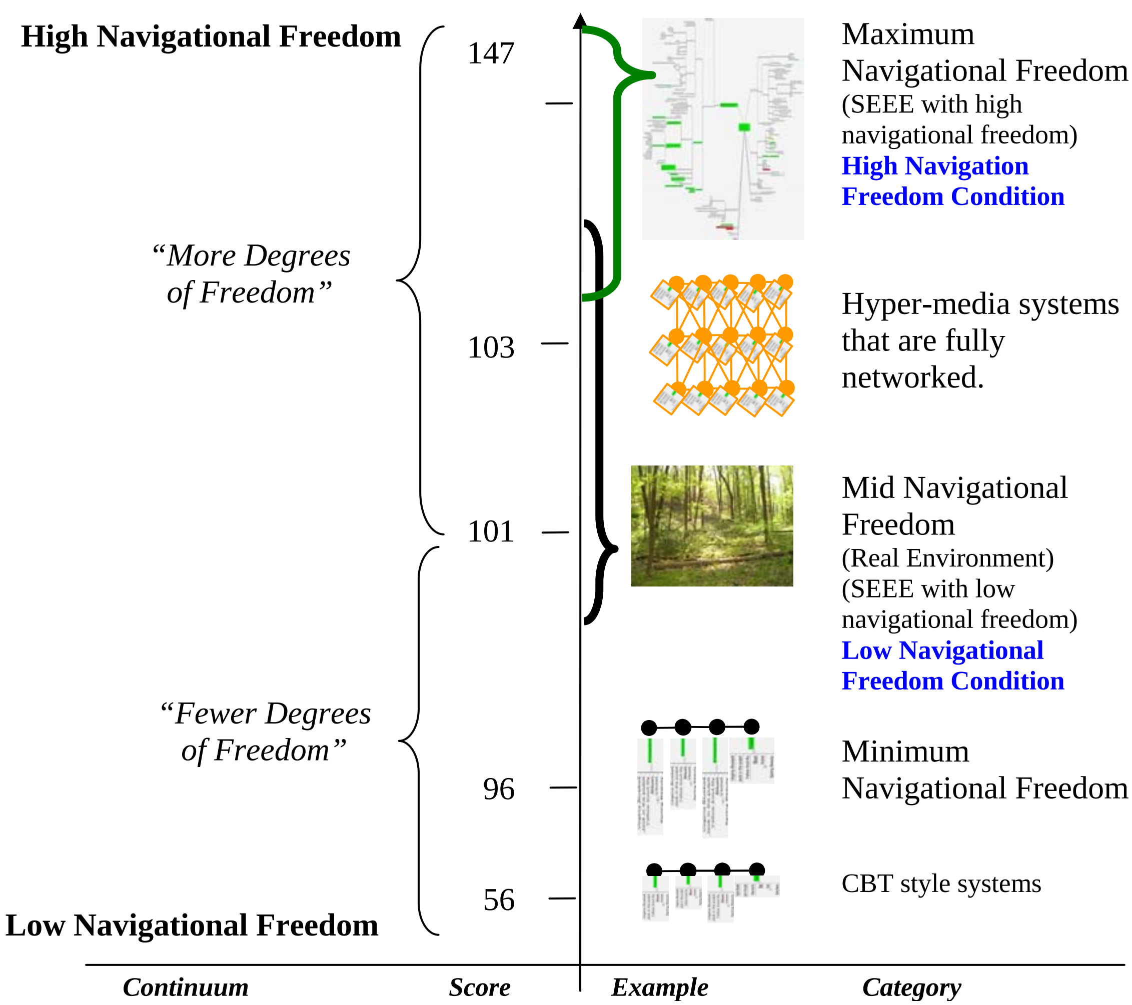
Navigational freedom can be expressed in a continuum—from the low level to the high level—and then scaled to obtain a salience score. ***Navigational freedom allows active, user-initiated inquiry and exploration in context.*** For example, a linear wizard system is an excellent navigational choice for drill and practice, so if the user wants to memorize the times-tables, it would be an excellent choice.

Table 2. SEEE Navigational Freedom Continuum Matrix

		Navigational Freedom Category		
Context Category		**Real (Standard)**	**SEEE (High navigational freedom)**	**SEEE (Low navigational freedom)**
	Object (Flower)	Can bend down, kneel down for a closer look. Use of Expert Naturalist Guide, books, worksheets and tools, binoculars and magnifying glass, to facilitate inquiry	Use the arrow keys, mouse and Space bar for selection. UI methods to facilitate inquiry down the object's UI fact hierarchy.	Same as the SEEE high navigational condition.
	Ground (Hillside)	Ego-centric, use of trail, signs and natural affordances, up, down, follow the stream. Guided inquiry. The Guide will point to objects of interest along the way, and children will point out objects they find.	Ego-centric, use arrow keys and mouse to move along the trails or off the trails, and respond to affordances, such as up, down, follow the stream or use other landmarks. User can also enter a Fly mode for an ego-centric view. Augmented with sound to simulate the guide's monologue for contextually triggered information delivery in UI called Sprites.	Same as the SEEE high navigational condition, except that the system will constrain the motion to the trail. The students will not be allowed to leave the trail. This is more like the real field trip, as it is a guided exploration and inquiry along the path.
	Ecological Environment (Trillium Trail)	Exo-centric, use of a paper map.	Exo-centric, use Birds Eye view in the fly mode.	None.

The rationale for Graph 2 is to show that there are ranges of navigational possibilities, perhaps with some overlap, and that this presentation may be helpful when selecting a technique and the empirical test conditions, especially for future research. Each navigation mode was decomposed into its attributes with a common filter. The SEEE Navigational Freedom Scale, as shown in Graph 2, presents proxy values for navigational freedom on a scale, but it does not imply that one method of navigation is absolutely better than another method. Each navigational method will have situations where it outperforms the others, as it is always dependent on the user's goals and tasks.

Graph 2. SEEE Navigational Freedom Scale



The range for each attribute was (0-10). The total score represents an attribute's rank and order on the continuum. For this research, it will be necessary to choose ***two points*** that are representative of a ***low fidelity low navigational freedom*** (score of 101) and a ***high***

navigational freedom (score of 147) as navigational representations of the system to be used for comparison. The SEEE system is set to two different levels of navigational freedom, one low and one high. One condition will have high navigational freedom, with a salience score scaled to 147, and the condition of low navigational freedom will have a salience score scaled to 101.

Example 1: CBT: Lowest navigational freedom (salience score of 56).

Consider the following example of a CBT: a linear wizard. In this system, the child can select to navigate down the objects fact hierarchy or to select the next object, or to exit.

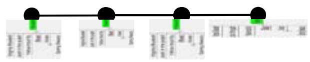


Figure 24: A diagrammatic representation of a CBT minimum navigational freedom.

Notice the variables and navigational attributes:

NOD= Number of Object Nodes: 100% plants (10)

NDOF=Navigational Degrees of Freedom features:

- **FH**= Possible to explore down the object fact hierarchy (100%): (10)
- **NO**=Select to go to the next object: (10)
- **PO**=Select to go back to the previous object: (0)
- **JTO**=Select to jump to any of the other objects (0)
- **IC**= Passive inquiry on context: (3). Constant variable, limited passive voice. (e.g. "Do you notice if it is moist or dry?")
- **YAHM**=Show a You Are Here map for context (3). Facilitate exo-centric wayfinding.
- **RGUD**=Redundancy gains of up / down (0)
- **RGRLR**= Redundancy gains of left / right (0)
- **RGFOVS**= Redundancy gains of New Frame of View and Same Scale: Look up/down?: (0)
- **RGNSFOV**= Redundancy gains of New Scale and Frame of View: Fly Mode or Zoom-Out (bird): Shrink Mode or Zoom-In (bee): (0)
- **PD**=User can choose programmer-allowed direction (10) "must stay on trail"
- **NPD**=User can choose non-programmer allowed direction (0) "off-trail"
- **TT**= Time -ravel forward or back: (0)
- **E**=Exit at any time: (10)

Example 2: Low navigational freedom (salience score of 96).

This is when the user follows the route passively, with no choice, but will benefit from the context of the environment and route.

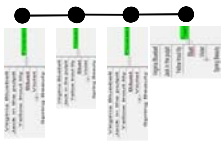


Figure 25: A diagrammatic representation of a SEEE with low navigational freedom.

Notice the variables and navigational attributes:

NOD= Number of Object Nodes: 100% plants (10)

NDOF=Navigational Degrees of Freedom features:

- **FH**= Possible to explore down the object fact hierarchy (100%): (10)
- **NO**=Select to go to the next object: (10)
- **PO**=Select to go back to the previous object (10)
- **JTO**=Select to jump to any of the other objects (0).
- **IC**= Passive inquiry on context: (3). Constant variable, limited passive voice. (e.g. “Do you notice if it is moist or dry?”)
- **YAHM**=Show a You Are Here map for context (3). Facilitate exo-centric way-finding.
- **RGUD**=Redundancy gains of up / down (10)
- **RGRLR**= Redundancy gains of left / right (10)
- **RGFOVS**= Redundancy gains of New Frame of View and Same Scale: Look up / down?: (10)
- **RGNSFOV**= Redundancy gains of New Scale and Frame of View: Fly Mode or Zoom-Out (bird): Shrink Mode or Zoom-In (bee): (0)
- **PD**=User can choose programmer-allowed direction (10) “must stay on trail.”
- **NPD**=User can choose non-programmer allowed direction (0) “off-trail”
- **TT**= Time-travel forward or back; (0)
- **E**=Exit at any time: (10)

Example 3: SEEE low navigational freedom and real field trip (salience score of 101).

Figure 26: A diagrammatic representation of a real-world field trip with mid-level navigational freedom.

Notice the variables and navigational attributes:

NOD= Number of Object Nodes: 100 plants (10)

NDOF=Navigational Degrees of Freedom features:

- **FH**= Possible to explore down the object fact hierarchy (100%): (10)
- **NO**=Select to go to the next object: (10)
- **PO**=Select to go back to the previous object :(10)
- **JTO**=Select to jump to any of the other objects: (0).
- **IC**= Passive inquiry on context: (10). Constant variable, limited passive voice. (e.g. "Do you notice if it is moist or dry?")
- **YAHM**=Show a You Are Here map for context (5). Facilitate exo-centric way-finding. (e.g.Paper map in the field and a GPS tool)
- **RGUD**=Redundancy gains of up / down: (10)
- **RGRLR**= Redundancy gains of left / right: (10)
- **RGFOVS**= Redundancy gains of New Frame of View and Same Scale: Look up / down?: (10)
- **RGNSFOV**= Redundancy gains of New Scale and Frame of View: Fly Mode or Zoom-Out (bird): Shrink Mode or Zoom-In (bee): (3) (Magnifying glass?)
- **PD**=User can choose programmer-allowed direction: (10) "must stay on trail."
- **NPD**=User can choose non-programmer allowed direction (0) "off-trail"
- **TT**= Time-travel forward or back: (0)
- **E**=Exit at any time: (10)

Example 4: Mid to high navigational freedom: hypermedia system (HMS). (salience score of 103).

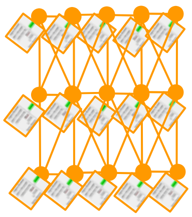


Figure 27: A diagrammatic representation of an HMS.

Notice the variables and navigational attributes:

NOD= Number of Object Nodes: 100 plants (10)

NDOF=Navigational Degrees of Freedom features:

- **FH**= Possible to explore down the object fact hierarchy (100%): (10)
- **NO**=Select to go to the next object: (10)
- **PO**=Select to go back to the previous object (10)
- **JTO**=Select to jump to any of the other objects (10)
- **IC**=Passive inquiry on context: (3). Constant variable, limited passive voice. (e.g. “Do you notice if it is moist or dry?”)
- **YAHM**=Show a You Are Here map for context (3). Facilitate exo-centric way-finding (same overlay as in the CBT)
- **RGUD**=Redundancy gains of up / down: (0)
- **RGRLR**= Redundancy gains of left / right: (0)
- **RGFOVS**= Redundancy gains of New Frame of View and Same Scale: Look up / down?: (10) (will design for it).
- **RGNSFOV**= Redundancy gains of New Scale and Frame of View: Fly Mode or Zoom-Out (bird); Shrink Mode or Zoom-In (bee): (7) Magnifying glass? (could design for it).
- **PD**=User can choose programmer-allowed direction (10) “must stay on trail”
- **NPD**=User can choose non-programmer allowed direction (0) “off-trail”
- **TT**= Time-travel forward or back:(10) (could design for it).
- **E**=Exit at any time: (10)

Example 5: Maximum navigational freedom SEEE (salience score of 147).

Figure 28: A diagrammatic representation of an SEEE.

Notice the variables and navigational attributes:

NOD= Number of Object Nodes: 100 plants (10)

NDOF=Navigational Degrees of Freedom features:

- **FH**= Possible to explore down the object fact hierarchy (100%): (10)
- **NO**=Select to go to the next object: (10)
- **PO**=Select to go back to the previous object: (10)
- **JTO**=Select to jump to any of the other objects: (7)
- **IC**=Passive inquiry on context: (10). Constant variable, limited passive voice. (e.g.. “Do you notice if it is moist or dry?”)
- **YAHM**=Show a You Are Here map for context: (10). Facilitate exo-centric wayfinding. (real time and continuous).
- **RGUD**=Redundancy gains of up / down (10)
- **RGRLR**= Redundancy gains of left / right (10)
- **RGFOVS**= Redundancy gains of New Frame of View and Same Scale: Look up / down?: (10)
- **RGNSFOV**= Redundancy gains of New Scale and Frame of View: Fly Mode or Zoom-Out (bird); Shrink Mode or Zoom-In (bee): (10) Magnifying glass?
- **PD**=User can choose programmer-allowed direction: (10) “augmented overlay”
- **NPD**=User can choose non-programmer allowed direction: (10) “off-trail”
- **TT**= Time-travel forward or back: (10)
- **E**=Exit at any time: (10)

7. Pilot Study: An Ethnographic Analysis

The first prototype system of the Virtual Trillium Trail is discussed and evaluated in this chapter. The application had to work well with young children, and so it was first piloted in this study. One proven method to ensure usability is a User-Centered Design (UCD) approach. Activity analysis in relation to the larger user goals of intrinsic discovery based learning was conducted. The pilot study's field observation of students learning in the real world on a field trip to the real Trillium Trail proved invaluable for the Main Study. Evidence of the Teachable Moment and the extreme personalization of the curriculum ontology by the teacher were key observations. Salient Events became critical user interface (UI) design components in the Main Study SEEE. The data gathered on personally meaningful events contributed to an understanding of how real field trips could be augmented by the virtual field trips, first to prime before and to reinforce after, for statistically significant transfer effects of procedural knowledge and activity.

The ethnographic report provides deep understanding of the interacting dynamics among the teacher, student, and knowledge-seeking behavior in the context of the environments. Such analysis is a required first step, not only for a deep understanding of the student, but also as a way to generate insights for software design and development. Thus, a detailed ethnographic observation, analysis, and report of the real-world activities are provided. Educators and software designers alike should find the ethnographic description valuable, as it details the activity. The primary focus on user activity in-situ is to inform the child-computer interaction software design process. Only such detailed observational studies allow the designer to identify the *Salient Events*, environmental factors, or the social interactions, context, tools, and tool-use required for successful software design and development. To facilitate a deeper understanding of the experiences, the subjects participated in both the real field trip and the virtual field trip in a counterbalanced design. This approach was required to give a meaningful interpretation of the impact the order and the environment may have on the overall experience; then, a post-experience comparison and contrast interview and survey was required to aid in understanding the child's perceptions and attitudes of the two experiences.

7.1. Pilot Study Research Design Overview

The ethnographic study involved video- and audiotape recordings, photographs, and field-notes of the teacher and student activity in both the real and virtual field trip environments. Each experience was limited to one-and-a-half hours, with the same guide. The guide was a trained naturalist and educational expert from the Audubon Society of Western Pennsylvania. There were six students in each group, for twelve students. In this way, the video documented activity in the field, tasks of exploration, inquiry, questions, learning, and responses to new knowledge. The real field trip was to the Trillium Trail Wildflower Reserve, Pittsburgh, PA. The virtual field trip was to a computer lab-classroom in the School of Information Science at the University of Pittsburgh, where the software was installed in a PC-lab. Each child had access to his / her own computer, and could interact with the guide and each other at will.

7.1.1 Pilot Study Design

Group	First Experience	Test	Second Experience	Microworld Activity	Post Experience Comparison Attitude Survey
Real-Virtual Group	***Real Experience*** In-Situ Maps Count of Salient Objects Total and Plants Only	Post-test for Real	***Virtual Experience*** In-Situ Maps Count of Salient Objects Total and Plants Only	*Microworld Creation Activity & Artwork*	*Post Experience Interview & Survey*
Virtual-Real Group	***Virtual Experience*** In-Situ Maps Count of Salient Objects Total and Plants Only	Post-test for Virtual	***Real Experience*** In-Situ Maps Count of Salient Objects Total and Plants Only	*Microworld Creation Activity & Artwork*	*Post Experience Interview & Survey*

Figure 29: Counterbalanced Design with post-test for direct comparison.

7.1.2 Pilot Study Counterbalance Design for Ethnographic Analysis

Group	First Experience	Second Experience	Post-Experience Evaluation
Real-Virtual Group	***Real Experience*** Video Documentary	***Virtual Experience*** Video Documentary	- Interview & Survey
Virtual-Real Group	***Virtual Experience*** Video Documentary	***Real Experience*** Video Documentary	- Interview & Survey

Figure 30: Study One Counterbalanced Design

The main research aim of this study was to compare and contrast the two environments. The two environments were the real field trip and the virtual field trip, all other factors constant. In such a design, there is no need for a separate control groups, as each subject acts as his / her own control, counterbalancing the order in such treatments as are assigned (Siegel, 1956, p. 62). The two groups experienced both conditions at different times, and then compared their impressions and perceptions in a post-experience interview and survey. The main outcome of this design is to present the most accurate comparison possible from the student's perspective.

7.2. Pilot Study Population

A volunteer sample (N = 12) was drawn from a local suburban public school district population, located outside Pittsburgh, Pennsylvania. The district population is diverse but biased towards an upper socioeconomic profile. It is a high-achieving Blue Ribbon School, with Grade 4 District Report Card noted as “proficient and above"; test scores for the PSSAs, as reported for the school district, were Math, 93rd percentile and Reading, 86th percentile (Pennsylvania Department of Education, 2007). Class sizes range from 18 to 24 students per teacher. It has a very active parent-teacher organization, with high parental volunteer involvement (10% of population and almost a 1:1 parent-teacher ratio), and highly respected teachers, with virtually no turnover. It offers computer classes for all students, white-board technology, and a wide variety of computer technology integrated into the classrooms. Furthermore, the students and school have access to local parks with integrated Audubon Society directed field trips at all grade levels, to enrich science and ecology lessons. All students have participated in various real field trips to many of the local parks and nature reserves with the naturalists and parent volunteers throughout their elementary school experience.

7.2.1 Pilot Study Sample

From this population, twelve students volunteered for the study. All were surveyed using a Likert scale prior to the experience to create a user profile. The sample reported expert levels of *Computer Skill* (100% owned PCs, $M = 8.5$, Median rank = 10/10), *video gaming* (75% owned video games, and 100% had used video games), and *Enjoyment of Nature* (100% had been to Trillium Trail, $M = 8.5$, Median rank = 10/10). Thus, *Computer Knowledge* and *Enjoyment of Nature* descriptives between the groups are identical and high.

A t-Test for *Computer Knowledge* shows no difference between the user profile results: $t(10) = 0.00$, $p = 1.00$. A Mann-Whitney U-Test, as a more appropriate statistic for such ordinal data, shows $U = 16$, $p = 0.8103$. A t-Test for *Enjoyment of Nature* shows no difference between the test results: $t(10) = -0.14$, $p = 0.891$. A Mann-Whitney U-Test, as a more appropriate statistic for such ordinal data, shows $U = 20.5$, $p = 0.749$. The descriptive, parametric, and nonparametric statistics proved that there are no observed differences between the two groups in terms of *Computer Skill* and *Enjoyment of Nature*. Thus the profiles in these two dimensions between the two groups are the same.

$$H_0: \mu \text{ Pre-experience Profile}_{\text{(Real-Virtual group)}} = \mu \text{ Pre-experience Profile}_{\text{(Virtual-Real group)}}$$

All twelve students were from the same elementary school, and ten of the twelve students were from the same class with an expert science teacher. The entire academic year (September 2006 to May 2007) prepared for a real field trip to Trillium Trail. Random sampling from the population is impossible due to Federal Regulations that protect human subjects in research, and random assignment was impossible due to the practical constraint of working with children and very busy families. However, we argue that this volunteer sample is representative of a user profile of high-achieving, suburban, public schools with fourth graders interested in computers, video games, and nature. Furthermore, if an experimental system cannot perform adequately under such ideal conditions, it certainly would not under challenging conditions, and so, for the purpose of software design and development, this user profile was ideal for the pilot study. This volunteer sample is representative of high-achieving, suburban, public schools with fourth graders interested in computers, video games, and nature. The statistics prove that the sample groups were homogeneous in the dimensions of investigative concern and ideal for a statistical blocking strategy that can be superior to random assignment for reducing noise. Thus, the claim is that the sample is homogeneous, had the same level of knowledge and experience prior to the study, and may be generalized to populations of similar profiles.

7.3. Pilot Study Materials

7.3.1 Educational Curriculum

For a full description of the educational curriculum, see the SEEE system above in Chapter 5. The educational curriculum was based on the fourth grade *Natural Communities* from the Audubon Society of Western Pennsylvania.

7.3.2 Pilot Study Post-test on Educational Facts

The post-test was a fifteen-question test derived from the Audubon Society's *Natural Communities* curriculum. Additionally, a fourth-grade teacher who was a science content expert reviewed the tests prior to use and evaluated. The objective of the teacher evaluation was to help refine and improve the test, as well as to help determine pre-experience curriculum exposure. The rationale was to co-design the test to avoid floor or ceiling effects, priming effects, and the time and cost of a pre-test. Based on five years of teaching experience including the field trips, the teacher expected that the students should know the names of *at least two flowers* after the real Trillium Trail field trip; no tree or bush names were expected to be learned. The post-test was designed to take advantage of that gap (Questions 1–6). They were expected to know about watersheds and the formation of valleys, habitats, photosynthesis, and pollination, but to gain deeper understanding in the field trip. The facts and concepts related to plant adaptation (Question 7), forest canopy and forest community, and biotic and abiotic interconnections (Questions 9–12) with an emphasis on the dynamic interactions of natural form and function (Question 14) were not covered in depth before the field trip. Since the Audubon curriculum and field trip offered this broader experience in the spatial context with many types of plants, trees, and bushes, as well as opportunities to directly and individually experience the dynamics found in the forest ecology, the post-test was designed to take advantage of that gap. The post-test was also designed with open-ended essays and a drawing activity (Questions 8, 13, and 15).

Additionally, the Audubon educators reviewed and helped to refine the post-test. The post-test asked each child to name as many trees, bushes, and plants they knew in the local parks. Test activities, such as fill-in-the-blank and connecting lines from text to parts of drawings, comprised the factual and conceptual parts of the test. To capture both their knowledge and personal value of forest ecologies and dynamics, they were requested to write a story and draw a picture of a park, forest, or flower; finally, they were asked to describe why such places are valuable.

All tests were administered after the first experience. Thus, one group completed the post-test after the real field trip, and the other group completed it after the virtual field trip. Both groups received the same test, (Figure 29).

7.3.3 Pilot Study Post-Experience Comparison

After the completion of both experiences, and to capture emotional, affective, and attitudinal responses to the two experiences, an interview consisting of twelve open-ended questions and a survey of fourteen closed questions was administered. Re-printed below are the interview and survey questions. Each question was asked for each experience, real and virtual, so there are two results sets for each question per student. A 5-point Likert Scale was used: (1 = Not at all, 2 = Somewhat, 3 = Average, 4 = Mostly, 5 = A great deal). The results were used to compare and contrast the real and virtual experiences.

7.3.3.1 Pilot study interview

1. What did you enjoy most on the *Real Field Trip*?
2. What did you dislike most about the *Real Field Trip*?
3. What did you enjoy the most in the *Virtual Field Trip*?
4. What did you dislike the most about the *Virtual Field Trip*?
5. How would you improve the *Real Field Trip*?
6. How would you improve the *Virtual Field Trip*?
7. Which *Field Trip* did you learn more from? What did you learn?
8. Describe your ideal *Real Field Trip*.
9. Describe your ideal *Virtual Field Trip*.
10. Describe how you felt in the *Real Field Trip*.
11. Describe how you felt in the *Virtual Field Trip*.
12. Which would you rather go on if you had a choice? Why?

7.3.3.2 Pilot study survey

First rate [1 to 5] for the Real Field Trip, then rate for the Virtual Field Trip.

1. I was able to explore more in the (*Real Field Trip* | *Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
2. I was able to inquire – ask more questions & get answers in the (*Real Field Trip* | *Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
3. I was able to learn more in the (*Real Field Trip* | *Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]

4. I experienced a heightened sense of curiosity in the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
5. I experienced an emotional sense of calm in the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
6. I experienced excitement in the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
7. I experienced awe and wonder in the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
8. I experienced frustration in the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
9. I experienced disinterest in the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
10. I want to create something like what I experienced from the (*Real Field Trip | Virtual Field Trip*) field trip. [1, 2, 3, 4, 5]
11. I want to share this experience (*Real Field Trip | Virtual Field Trip*) with my friends. [1, 2, 3, 4, 5]
12. Do you want to re-experience the (*Real Field Trip | Virtual Field Trip*) field trip? [1, 2, 3, 4, 5]
13. Did you experience a sense of presence or of "being there" in the (*Real Field Trip | Virtual Field Trip*) field trip? [1, 2, 3, 4, 5]
14. Did you experience a sense of beauty in the (*Real Field Trip | Virtual Field Trip*) field trip? [1, 2, 3, 4, 5]

7.4. Pilot Study Procedure

The experiment required three weekends in early May 2007, when the real flowers were in full bloom. All volunteers were given a demographic survey prior to the experience. These were collected before the first field trip. Each subject was given a unique number, personal map, and wildflower field guide book (Thieret, Niering & Olmstead, 2001). They were instructed to annotate their map for items of personal interest, to use their field guide books to look up information of interest, and to listen and ask questions. As the students knew that 36 plants had note-cards next to them with facts, it became at times a self-directed goal to find the cards, but was not an explicit instruction. After the first field trip, their maps were collected, annotated with the student's numbered, and they were given a post-test on the facts and concepts presented in the field trip educational unit. All map annotation data was recorded per student for the first experience. On the second field trip, real or virtual, each map was returned to the matching student by number. Depending on the group assignment, the subjects experienced the alternative environment. After the second field trip, the maps were collected, annotations recorded, and an attitudinal interview and survey were administered. As can be seen from Figure 31 below, the activity in the two conditions is very similar. The only differences are those relating to the innate differences in the environments.

Real Field Trip	**Virtual Field Trip**
1) Natural Communities Curriculum 2) 6 children in group 3) With peers 4) Expert Guide – Audubon 5) Parents – each child's 6) Tools: a. wildflower field guide reference book b. map 7) Augmentation: a. note cards on the trail next to plant i. schematic drawings ii. facts 8) There is a path to follow 9) Child **may NOT go off path** 10) Child **can NOT** explore at will 11) Guide points out plants, animals and insects of interest along the way – passive learning – but it also triggers questions. The guide may point out items of interest in context. **12) Guide answers child-initiated questions at the time of inquiry and to the depth desired.**	1) Natural Communities Curriculum 2) 6 children in group 3) With peers 4) Expert Guide – Audubon 5) Parents – each child's 6) Tools: a. wildflower field guide reference book b. map 7) Augmentation: a. virtual note cards on the virtual trail next to virtual plant i. schematic drawings ii. facts 8) There is a virtual path to follow **9)** Child **may go off path** **10)** Child may explore at will: **fly, jump off cliffs, travel through the tree canopy and play in water** 11) Real guide, (same guide from the real field trip – not an avatar), will not point out animals or insects, but points out plants of interest along the way – passive learning – but it also triggers questions. The guide may point out items of interest in context. **12) Guide and the UI will respond and allow the child to inquire at will – breadth and depth.**

13) Surprises and *Salient Events* - animals in the environment or unexpected finds provide unexpected and abrupt changes to the lesson flow	13) **Surprises and *Salient Events* – none in this prototype.**

Figure 31: Comparison of the real and the virtual sequence of events.

7.5. Observation for the Real Field Trip

The real field trip occurred in early May 2007, at Trillium Trial Wildflower Reserve, Fox Chapel, PA. The real world field trip wass guide-facilitated. The expert naturalist guide, has extensive experience in conducting these educational activities with Beechwood Farms and many schools, and is a familiar and a much-adored face to the children. Typically, children carry their journal, field guides, and maps, and stop to inquire about plants that have a note card next to them on one of the many foot trails in the reserve. They also gesture, by pointing to and naming plants that they know. If they gesture but misidentify, the guide or peers correct them. If they are interested in but do not know the name of a plant or animal, they still point and ask the guide for information. Sometimes, the guide will see items of interest that the children do not notice, and so the guild will point out these missed items of importance.

The guide points out items of interest and tells stories about the topography, geography and ecology and how the form of the land influences the functions and interactions of the land, plants, and animals. Watershed information is interwoven into the stories. Biotic and abiotic interaction is covered, as are niches, life cycles, food-webs, photosynthesis, pollination and symbiotic relationships of life in the forest. Children are encouraged to ask questions. Most of the time, the guide led, and the children followed. The trails were followed and the children usually walked in line or clustered in pairs. Many times the guide would stop on the trail and ask for them to form a circle around her so they could all see, then she would point to something and ask if anyone knew what it was. Each time, she ensured that a different child was called upon. She was particularly attentive to students who were not really engaged and tried to connect to them

The guide would encourage the children to observe, touch, smell, and listen to their environment. She would model behavior and ask the children to do as she did. In this way, the multiple signals from the environment and the individuals' senses were integrated for learning. for example, one such lesson was on a plant called Cleaver, commonly referred to as bed-straw. The guide picked a sample of the plant and placed it on a child's shirt, where it stuck. All children were allowed to pick a small sample and place it on each other. There was much delight and giggling as the children got to participate. Then they were encouraged to think about the reasons why the plant could stick. The children hypothesized about the structure of the plant—it had Velcro-like barbs—and the reason for such an adaptation. It was this plant's adaptation that allowed the plant's seeds to attach to animals and thus use the animals for transport. Other adaptations for seed transport were discussed, such as the dandelion and thistles' adaptation for wind-born seeds. In this way, observation, touch, emotion, and social factors were integrated into the lessons.

Smell, as a sense, was encouraged as opportunity presented. Some plants were sweet-smelling, some repulsive, and others bitter, and each was sampled and discussed as having a role or reason, such as to attract insects for pollination or to repel a herbivore. Other interesting plant-pollination strategies, such as the use of violet (ultraviolet) colored lines on petals to show insects the route and the place to find the nectar and thus the pollen, were discussed when serendipitously found. The use of taste was carefully introduced. For example, an invasive species called garlic mustard, which is a plant that is edible and one that should be removed anyway, as it is crowding out local, indigenous plants, was allowed to be picked and tasted. Each child was allowed to take a sample to crush and smell – some did take a small bite — yet all were strongly discouraged from harvesting wild plants on their own, due to the poisonous populations found locally. Many students were intensely interested in which plants they could eat.

There were many times when one child found something interesting, like a spider, and others did not. The guide was continuously relating the finds to the educational curriculum, the forest, the watersheds, the interaction of the abiotic and biotic dynamics, and how to identify each plant, where the plant lived, and any interesting facts about the plant. The observation of the students was one of constant integration and organization of the new information.

Figure 32: Photographs from the real field trip at Trillium Trail in May 2007.

Consider the following example from the research notes, as it is representative of the type of conversation observed on the real field trip, one in which the guide leads the children through the educational lesson found in the nature reserve. Group 0 was the code for the *Real-Virtual Group Order*, and each subject is only identified by number.

> Guide: *"OK, does anyone know what this plant is?"*
> Group 0: *"Umbrella Plant, May-apple, Mayflower, Mandrake"*
> Guide: *"Wow, all of you are so smart, this plant is known by all of those names. Look around, notice we are low in the valley, we are on the north side of the range, more shady than the south side* – she points across to the south-facing slope - *This plant likes the moist, nutrient-rich, soil down here by the stream in the Herb layer of the Forest*– she points down and crouches close to the ground. *The plant likes the cool wet areas. Can anyone tell me what is so special about this plant?"*
> S7: *"It is used to cure cancer?"*
> S9: *"It is my favorite, it is so pretty!"*
> S10: *"Doesn't the turtle eat its fruit?"*
> Guide: *"What good answers! You are all right, and did you know that, while this plant is being researched to provide medicine for skin cancer, it is very poisonous, so don't eat it. The flowers only bloom when it is two years old, see how the younger plants only have one stem, and the older ones have two? The flower grows between the Y of the two stems. The flower is white and the leaves*

are shaped in the…. What is this called?" - she holds the leaf for the children to see.
Group 0: *"Umbrella… whorled?"*
Guide: *"Yeah, the umbrella is whorled. Whorled is the word used to describe this pattern of leaves. When the flower matures, who knows why this plant makes a flower? The purpose and the reason?"*
Group 0: *"To make seeds, to attract a bee, pollination, reproduce."*
Guide: *"Right again! And to feed the animals. Right? Even though this plant is poisonous to us, the fruit when ripe is not, and the Pennsylvania Turtle, sometimes a deer, will come along in late summer, early autumn and find a nice, fat, juicy berry."*
Children look closer and express excitement and interest with sounds.
Guide: *"And who can tell me what that turtle does? When it finds that nice, fat, juicy berry?"*
Group 0: Now very excited, all chime in, *"He eats it!!!!"*
Guide: *"That's right! Eats it! And then what?"*
The children are puzzled, not knowing what to say.
Guide: *"Well, he walks a little, he is a little turtle, so he does not walk far, and then, that is right - turtle droppings – it is the perfect fertilizer for a new plant to grow in! So, this plant and many plants rely on other animals to pollinate and then to plant their seeds. They make their flowers pretty and smell, so they can attract bees and other insects to their nectar and pollen. They make fruit taste sweet so that animals will eat it and help to distribute seeds. And this is how the plants and animals are connected, it is a symbiotic relationship. Who can tell me about another 'symbiotic' relationship?...."*

Note the emotional encouragement and confirmation that the guide gives to the children. There was positive re-enforcement and approval throughout the hike, but it was never annoying or superficial. The bond that the children have with guide is based on respect for her knowledge and love for her kindness, a critical relationship. They are eager to participate, do not fear offering a wrong answer, and so can take many guesses. There is no risk for a mistake, as it is just kindly corrected and a new effort is encouraged. Facts, information, and stories are added, and are viewed as part of a normal, positive, constructive, and respectful dialogue. The process is first a question, then an answer, always a social acknowledgment (reward), more factual additions, demonstrations with as many senses integrated as possible, anchoring new data to salient attributes, a new question on the reason why, or how, then an answer, always an emotional affirmation (reward), and so on and so forth.

Within the one and a half hours, the guide introduced concepts of importance, told stories, and answered questions. These were spontaneous, dynamic micro-lessons embedded in the activity inside a geo-spatial macro-context, representing the embodiment of the educational curriculum's ontology and integrated into the multi-sensory activity of a field trip. The guide covered one story in each micro-lesson and then moved on. She controlled the pace, direction, and way-finding activity of both the hike and the lesson. She relied on the abundance of material in the natural environment for content and context, maximizing the opportunities to weave the larger lessons into the spontaneous finds of the moment, as well as integrating student-initiated discussions. Effortlessly, the guide was able to *"spin"* the curriculum's factual and conceptual ontology to meet the children's needs of the moment, based on their interest level, spontaneous events, or guide-initiated finds. Thus, the semantic navigation of curriculum ontology on the hike was surprisingly hyperbolic, but not to the point where it disintegrated into chaos or confusion.

The physical navigation on the hike was linear, as children followed the guide. They stayed on the trail or the stream, and the guide controlled the pace and the direction. Children took turns, and focused on each other's finds at given points in time. This was the fourth year on such field trips, so the students understood the expected behavior. The activity could also be a result of the physical environment, as there was a footpath to follow. They were in the same place at the same time and mostly perceptually and cognitively unified. Even when some children walked ahead, they stopped to call back to the guide and the group upon discovering interesting finds. Plants with factual note cards were in-place ahead of the group, as surprise finds and potential objects of discussion. Other non-planned items of interest, such as dead logs, rocks, animal tracks, pellets, and nests, were also in the environment and facilitated discussion. Additionally, there were moments of true salient surprise in the environment such as a bird, deer or frog that would suddenly appear. A knowledgeable and skilled guide integrated these unplanned events into the discussion effortlessly as a *Teachable Moment* (Bentley, 1995).

7.6. Observation for the Virtual Field Trip

The virtual field trip occurred at the University of Pittsburgh, School of Information Sciences PC computer lab classroom. This classroom is typical of many school computer labs, with workstations positioned in rows on desks and a projector system in the front of the room. This lab comfortably accommodates twelve students. There were two sessions, one for each of the groups' virtual field trips. Each group had six students, and each student had access to their own PC with a one eared headset, keyboard, and mouse. Each computer had the same version of the Virtual Trillium Trail software. The guide covered the same educational unit as in the real field trips. However, each experience was different at the micro-lesson level, as different students traveled on different paths, and found different plants and flowers. The guide controlled her PC and projected her system's images to a large screen in the front of the class using a common off-the-shelf overhead projector. In this way, the guide and students could share information at all times. The configuration is no different from the current state of technology in classrooms today. Parents and the researcher were able to sit behind the children and to passively observe and videotape.

None of the children required training or assistance. They all knew how to use a PC, mouse, and keyboard. As soon as they entered the room, they sat down and started to explore independently and without instruction. They did not wait for training, instructions, or the guide. Furthermore, many of them knew the special commands found in gaming software, and started to walk, run, fly, jump, and swim about the environment. This activity is very different from the real field trip, where they showed restraint. Most notable is the fact that, within moments, each child was in a virtually very different location — some in the stream, some on the *Lookout Rock* some on the ridge, some in the flood-plane, some in trees, some flying through the sky, and some jumping down the waterfall — each asking questions about their virtual environment at the same time. The guide had to be active, answering each child's question as needed. At times, she made efforts to pull the group together, but was only able to get them to glance up from their PCs to look at the projected image and listen to her information and answer her questions for a moment before returning to their explorations. The guide's stories were the same, but the children were not in the same – virtual – place as the guide; they were in their own location, each was in a unique, personal, virtual place.

At times, the students did share their finds with the class and the guide. So the rate of exploration and discovery increased, as did the activity, but the control of pace and direction by the guide was gone. Now, instead of leading the children, as she had done in the real field trip, she was following them – virtually — and following each of the six simultaneously. This is a critical difference for the teacher and style of learning activity. In the lab there was a fast, highly individualistic exploration, with individual, not group, spontaneous finds. The sharing of this information in the class with the guide was only possible if the peers were not too involved in their own adventures.

Figure 33: Photographs from the virtual field-trip, Virtual Trillium Trail, at the School of Information Science, University of Pittsburgh, May 2007.

The following example from the research notes is representative of the type of conversation observed in the virtual field trip and used to demonstrate the type of activity in the PC lab:

Guide: *“OK, first I am going to fly up into the sky to get a view of the valley, you can follow me on your PCs if you want or you can just watch up here. So, what do you see?”* – Guide navigates up for an aerial view of the valley.
Group 0: *“The river. The valley. The tops of the trees.”*
Guide: *“That’s right. The name of the river is Stony Creek and it is a tributary of Squaw Run, and Squaw Run is a tributary of What River?”*
Group 0: *“Oh, Oh, Allegheny! Yes, the Allegheny River!”*
Guide: *“That’s right! And the Allegheny River flows into the What?*
Group 0: *“Oh, Oh, Monongahela, no the Ohio, then the Mississippi, then into the Gulf of Mexico, the Atlantic Ocean, then all over the world”*
Guide: *“That’s right! Stony Creek, Squaw Run, The Allegheny, the Ohio, the Mississippi, the Gulf of Mexico, and the Atlantic, so we are standing, well virtually flying over the head-waters to the Mississippi! Isn’t that amazing!*
… What is a watershed and why is it important?”
Group 0: Not sure, a bit reserved, some guess - *“Plants and animals need water to live.”*
Guide: *“Yes… And?… So the plants and animals need water to live,… and a watershed is a place – a land formation -- that naturally collects rain water, like a bowl or a basin and then the rain water flows down the sides of the valley into the streams and rivers at the bottom of the valley.”*
…
Did you know that we only have valleys here, and not hills, it is called the Appalachian Plateau. The streams and rivers have over time, a long time, eroded the valleys. The plants’ roots help to hold the soil to the earth, and help to prevent severe erosion. The plants’ roots also help to filter and clean the water to make it pure.
…
So, we can also see what plants like water – see the ones close to the streams – like this… this Sycamore Tree, it likes the water, has a white flaky bark –“ The guide pointed to one of the trees that is visibly white and green, and not brown and green like the others, from above – “*We can fly down into the Forest to take a closer look”.* – The guide starts to fly down into the forest -
...
“This is the Forest Canopy, the tops of the trees. – “The guide stops at a close-up of the tree leaves – “*What do you notice about the different leaves here? What does the bark look like?”*
Group 0: *“White and flaky.”*
Guide: *“What animals do you think make their homes up here?”*
Group 0: *“Birds, insects, squirrels, raccoons…”*

The lessons are similar to the types of dialogue from the real field trip but make use of the software's ability to fly, showing the watershed from a different perspective. It also allows the guide to take the children into the leaf canopy of the trees and to see things that they can't see in the real forest. The other difference is that the perspective on the ground is much closer to the flowers than in the real field trip, and so all of the flowers' structures are magnified and in view for analysis.

> Child 7: *"Oh look I found a field of Bluebells!!!"*
> Group 0: *"Where?!?"*
> Child 7: *"Here in the flood-plane at the bottom of the valley"*
> Guide: *"Oh good! Let me see."* The guide approaches the student and looks over at her PC. *"Hmm, I think those are actually Bluets. See, they are very small, and have only four petals. There are some violets too."*
> Group 0: *"Where are they? How do I get there? I found it! There they are, and there are some Trilliums too!"*
> Guide: Takes some time to find the Bluebells on her PC - *"Look up here, here are Bluebells, see how the petals are shaped in tubes, how they hang down in clusters. Now look at her screen, see the Bluets, they are small, and have almost flat petals positioned in opposites and there are only four petals for each flower. It is a really good find, and now we all know the names of two blue flowers! Bluets are smaller with four petals, and Blue Bells are larger with clustered, hanging tubes. Thank you number 7."*

In an asynchronous way, the group interacted with their finds, their peers' finds, and the guide. From the perspective of an observer, it felt disjointed, yet individualistic. There is, of course, no smell, taste, touch, or the spontaneous finds of insects, animals, or birds in the virtual field trip as there was in the real, but the software allowed for full freedom of individual movement and supported independent exploration, discovery, and inquiry.

7.7. Pilot Study Results

7.7.1 Pilot Study Post-Test on Educational Facts

A post-test was administered after each field trip, real or virtual, to measure any learning differences, but not after combined conditions. The total post-test descriptive data for the *Real* field trip (M = 30.09, SD = 14.01, Median = 36.38) is similar to the post-test descriptive data for the *Virtual* field trip (M = 33.451, SD = 17.9, Median = 37.58). The t-Test result is nonsignificant, $t(10) = -0.36$, $p = 0.726$, two-tailed. A Mann-Whitney U-Test, as a more conservative statistic due to the skewed distributions and small sample size (Siegel, 1956), still indicates no significant difference in total test scores ($U = 25$, $p = 0.2980$).

H_0: μ Test $_{\text{(Real Field trip)}}$ = μ Test $_{\text{(Virtual Field trip)}}$

The test was evaluated on total points possible (0-100 points), and the questions were classified into three categories. *The Real Group* consisted of responses from subjects 1-6, and *The Virtual Group* consisted of responses from subjects 7-12. Subjects 5 and 6 did not complete the drawing or the essays, thus damping the descriptives for that group. The first and most straightforward category was the questions that dealt with *Facts* (Real μ=13.99 and Virtual μ=11.94). The second category dealt with *Concepts* (Real μ=2.98, Virtual μ=4.00). The last category dealt with the affective, which included the drawings, values, and the essays (Real μ=13.16, Virtual μ=16.00). The data on the post-test indicated that, for both groups, teacher expectations were exceeded (Expectation $\mu = 2 <$ virtual group test facts μ=11.94 < real group test facts μ=13.99), but as a volunteer group there may be sample bias as they were the exceptionally bright students of the class.

Thus, the two groups had statistically identical profiles and post-test scores after the first experience, and thus their activity in-situ was expected to be the same. Note that the tests only measured plants and content from the *Natural Communities* curriculum, and not all of the material that was encountered or learned, and so this result does not prove that all of the knowledge learned on the real field trip was captured or measured in the test, or that the environments or learning activity were the same. This is not asserting that the two experiences are identical. The real offered many experiences that were not in the virtual, such as getting wet in the stream, finding and touching a salamander, smelling the Red Trillium or Skunk Cabbage, tasting a plant such as Garlic Mustard.

The interesting question is: If you have a class of students with the same background, experience, profile, and knowledge, will their learning behavior, such as exploration and explicit recording activity, be the same or different in two such learning environments – the real and the virtual – especially if great care was taken, as we have done, to make the virtual match the real for curricular and ecological validity.

7.7.2 Pilot Study Interview Results

To compare and contrast the two experiences in qualitative depth, all subjects responded to an interview after experiencing both the real and the virtual field trips in a counterbalanced design. A sample of a subject's answers to an interview is re-printed here to show the type of comparison that was conducted (Example answers of Subject 1).

Please answer the following questions:

1. *What did you enjoy most on the Real Field Trip?*
   I enjoyed the different plants and the waterfall.

2. *What did you dislike most about the Real Field Trip?*
   We needed to stop a lot if any of the kids had questions.

3. *What did you enjoy the most in the Virtual Field Trip?*
   Being able to fly around and drop to the ground.

4. *What did you dislike the most about the Virtual Field Trip?*
   It was very slow graphics.

5. *How would you improve the Real Field Trip?*
   If there were animals to see that would be better.

6. *How would you improve the Virtual Field Trip?*
   Make the computer faster and the graphics better.

7. *Which Field Trip did you learn more from? What was it that you learned?*
   The real one, because Gabi showed us a lot and talked about a lot of things with us. I learned the names of lots of plants and trees.

8. *Describe your ideal Real Field Trip?*
   It would be a hike through a forest with lots of plants and animals that we could touch.

9. *Describe your ideal Virtual Field Trip?*
   It would be flying through a forest with lots of plants and even some monster plants, like skunk cabbages.

10. *Describe how you felt in the Real Field Trip.*
    I felt interested in the things around me and happy to be outside in nature.

11. *Describe how you felt in the Virtual Field Trip.*
    I felt like it was fun and something really different.

12. *Which would you rather go on if you had a choice? Why?*
    I would rather go on the virtual field trip because we can fly, and also because I can go at my own speed and stop and look at things or zoom on by.

The responses for the interview show interesting patterns and some surprising results. The first question asked the students about what they enjoyed most in the real field trip. There was an even split between sightings of plants and the context of the environment. The second question asked about what they disliked most in the real field trip. One-third reported nothing, but a few mentioned that they got tired or did not like the bugs. When asked about what they liked most in the virtual field trip, the students responded individually: some were excited about the ability to fly, others with walking; some mentioned that they could use their imagination to pretend to become a hawk or a rabbit in the woods, while others cited the advantage of being able to see things from different points of view, or that all of the flowers were in bloom and they could learn about those flowers. When questioned about what they disliked most in the virtual field-trip, seven of the twelve cited slow response times (the PC lab had old equipment), four cited getting lost, and one reported difficulty in reading the plant fact note cards. The students suggested improvements for both field trips. The ideal real field trip would include more animal sightings. Interestingly, the same suggestion held for the virtual field trip. They also suggested improved speed, interaction rates, and orientation capabilities for the virtual field-trip. Two suggested that collaboration components should be added, in the forms of a virtual guide, avatars to represent themselves and friends, and the ability to become a hawk, rabbit, or fish avatar. When asked which field trip they learned more from, ten out of twelve answered the real. The question asking the students to describe their ideal real or virtual field trip produced many ideas. The ability to touch, smell, and hear, and adding more plants and animals to the virtual experience were all cited as desirable. Subject 10 said, “Everything cool, great! Would love to do it (both real and virtual) again!” More students felt more excited and interested in the virtual (n = 8) than the real (n = 4), but overall positive emotions of *Happy*, *Calm*, *Peaceful*, *Interested*, *Fun* and *Excited* were reported. Only one reported a *Disinterested* response, and that was for the real field trip. When asked which field trip they would rather go on and why, more reported in favor of the virtual (n = 8) than the real (n = 3), with one not responding. Thus, even though they reported more learning in the real, they would rather repeat the virtual.

7.7.3 Pilot Study Survey Results

7.7.3.1 Significant results in favor of the real field trip

As this was a counterbalanced design, we have results from the 14-question survey that was administered to all twelve subjects and can be used to compare and contrast the real and virtual experiences. The survey used a 5-point Likert Scale (1 = Not at all, 2 = Somewhat, 3 = Average, 4 = Mostly, 5 = A great deal) to compare real and virtual field trip experience across each of the 14 dimensions measured. As this was a Likert-scale data set, a non-parametric Wilcoxon Signed Ranks Test was used. There were three statistically significant dimensions found. ***However, due to the high number of hypotheses tested (14), a more conservative interpretation is to reduce the p to 0.001 from the reported p value of 0.05. In the more conservative case, there is no difference between the real and virtual experience.***

Student Attitudes: The Real Field Trip superior to Virtual ($p < 0.05$)

- Learning higher
- Inquiry higher
- Presence higher

Table 3: *Real rated as superior to virtual (N = 12)*

	Real		Virtual		Wilcoxon
	Reported	Median	Reported	Median	p-value
Learning	"Mostly – A great deal"	4.50	"Somewhat"	2.00	0.010
Inquiry	"A great deal"	5.00	"Mostly"	4.00	0.026
Presence	"A great deal"	5.00	"Somewhat – Average"	2.50	0.017

Learning is rated as significantly higher in the real field trip than in the virtual (Table 3), supporting the interview results, but in contradiction to the post-test results. This is not to say that learning did not occur in the virtual, for it did *"Somewhat,"* and this ranking was framed in a direct comparison to the real. This is the first known direct comparison of real and virtual environments for discovery based learning. Learning was perceived as occurring in the real field trip, *"Mostly to A Great Deal."* This study has shown that there is no statistical difference in a post-test for in-curriculum, factual knowledge covered in both conditions, real or virtual. It has also shown that there is a student perception that more was learned in the real field trip. ***This study asserts that both conclusions are true.*** As the test only measured facts "in the curriculum," and as there was more information embedded in the real field trip, the children did indeed learn more "out of curriculum" information in the real field trip. The test simply did not capture all information learned. The ethnographic data supports this claim. There were unplanned learning events in the real field trip that were not duplicated in the virtual, and not tested in the post-test. The following is an excerpt from the real field trip ethnographic observation that demonstrates the activity embedded in the situation, and introduces the idea of *The Salamander Effect* as a type of *Salient Event*.

> *…in the real field trip a female student was walking in the stream, she said to a friend that there was "no life" in the stream, at which point the guide spun around and playfully said "Oh yeah?" The child was surprised, taken aback, all of the other children froze and watched, but once regaining her composure, the student said, "well that is what my mom told me, there is nothing alive in these streams." The guide proceeded to bend down, pick up a rock, turn it over and find a real, live salamander. At that point all of the children gasped, surprised, and gathered closely around the guide, asking questions, getting answers and taking turns touching the small creature. The guide then related the life of the salamander to the health of the stream, and the health of the stream, as it was clean of pollution and run-off, to the watershed, nature reserve and the healthy forest ecology. She pointed to the banks and showed how they were well composed from the abundance of plant, shrub, and tree roots. The relationship connecting the life a salamander in hand, beautiful glistening-auburn, to the health of the watershed was a powerful way to tie the experience back to the lesson on plants and to correct the child's misconception.*

The curriculum was about watersheds, forests, and plants. The post-test did not capture all of the spontaneously learned material in the real field trip. Such material as the salamander related discoveries, which were valuable yet extraneous to the in-test-set material. The *Virtual-Real Order Group* saw the salamander, and 100% of those subjects annotated their maps with that *Salient Event*, and thus affecting the *Total Map Annotations* data. A finding of this study is that the post-test scores were statistically identical, yet on the perceived dimension of *Learning*, it is significantly higher for the real field trip. Note that the post-test results reflect one experience, and the attitudes reflect both. Returning to the data in Table 3., there is a significant difference for *Inquiry*. Inquiry is associated here with asking questions, which is a very important activity in an educational context, real or virtual, thus a desirable trait of any learning environment or system. The real field trip rated higher in the ability to inquire than the virtual. This seems to contradict the observation in the lab, where the rate of questions went up, but as there were six children competing for the guide's attention and time, perhaps the perception of answered questions could have gone down as a result. The ethnography evidence supports this claim, where it was observed that the guide had to jump from one question to the next, and physically run around the room as each and every child was in a different location in the virtual environment. Finally, it is of no surprise that *Presence* is rated higher for the real field trip than for the virtual.

7.7.3.2 Results showing no statistical difference between field trips

Interestingly, and in all other dimensions, there is no statistical difference between the ratings of the real and virtual experiences. Using a Wilcoxon Signed Ranks Test statistic between the real and the virtual field trips, there are interesting trends in the data that need to be investigated and explored in greater depth. The data in Table 4. show the reported values, median, and p-value, ranked from highest to lowest by the order of the virtual median value.

The highest ranked value is for *Exploration* (Median = 5, "A great deal"), and the lowest is for *Disinterest* (Median = 1.00, "Not at all"). From a software design standpoint, this is exciting and encouraging data, as the "gold-standard" of parity with the real was obtained in these dimensions. Thus, the fact that *Exploration* was rated high and higher in absolute terms, while not significantly different from the real field trip, is still a very good result. The rating of *Disinterest* and *Frustration* as low on the scale are also very good results.

The claim is that the virtual environment matched the real for these dimensions, and in an order that is desirable for usability. The other high rankings (Median > 4, "Mostly" to "A great deal") are in: *Desire to Create, Sense of Excitement, Level of Curiosity, Desire to Re-experience,* and *Sense of Calm*. This is an interesting cluster for the design of virtual field-trip software and deserving of deeper investigation. Furthermore, the Wilcoxon Signed Ranks statistic is a conservative measurement of the data. The p-values of several of the rated factors are worth a closer inspection and future work, in the dimensions of *Exploration, Desire to Create*, and *Re-experience* ($p < 0.20$), and *Frustration* ($p < 0.10$).

Student Attitudes: Real and Virtual Ranked as the Statistically the Same

- Exploration
- Desire to Create
- Sense of Excitement
- Level of Curiosity
- Desire to Re-experience
- Sense of Calm
- Desire to Share
- Awe and Wonder
- Assessment of Beauty
- Level of Frustration
- Disinterest

Table 4: No Difference Between Real and Virtual Ratings (N=12)

No difference ($p > 0.05$)	Real		Virtual		Wilcoxon
	Reported	Median	Reported	Median	p-value
Exploration	"Mostly"	4.00	"A great deal"	5.00	0.196
Desire to Create	"Mostly-A great deal"	4.50	"Mostly-A great deal"	4.50	0.139
Sense of Excitement	"A great deal"	5.00	"Mostly-A great deal"	4.50	0.453
Level of Curiosity	"Mostly-A great deal"	4.50	"Mostly"	4.00	0.670
Re-experience	"Average"	3.00	"Mostly"	4.00	0.163
Sense of Calm	"A great deal"	5.00	"Mostly"	4.00	0.395
Desire to Share	"Average"	3.00	"Average-Mostly"	3.50	1.000
Awe and Wonder	"Mostly"	4.00	"Average"	3.00	0.577
Assessment of Beauty	"Mostly"	4.00	"Average"	3.00	0.257
Level of Frustration	"Not at all"	1.00	"Somewhat"	2.00	0.098
Disinterest	"Not at all-Some What"	1.50	"Not at all"	1.00	0.389

7.8. Discussion of Pilot Study Ethnographic Findings

The ethnographic study of the real-world field trip and the virtual field trip represented a research opportunity in software design and development, as well as in education. The opportunity was to compare and contrast learning activity in the two environments, real and virtual field trips, with the goal to improve future software designs of such systems for children. The main observation from the real-world field trip was that it was a linear, guide-led, and controlled path through the woods. The real-world field trip afforded exogenous events, at which point a skilled guide would spin the ontology of the curriculum around that event into a teachable moment. In comparison, the virtual field trip allowed each child to explore independently, making the guide move quickly around the PC lab to support the children. The guide could also bring information to their attention on her large projected screen for a class discussion, but everyone was in a different virtual "place" at the same time. In each of the environments, the curriculum ontology was "spun" around an event, usually triggered by the coalescence of the user and the environment at that moment as a *Salient Event*. The skilled guide spun the lesson's ontology and wove the micro-lesson of the moment into the macro-curricular structure, thus maximized the learning opportunity of any *Teachable-Moment*, (Bentley,1995).

7.9. Overview of the In-situ Empirical Part of the Pilot Study

Reported is an empirical evaluation and comparison of a map annotation learning activity between a real field trip and a photorealistic, virtual reality field trip of the same location, used for fourth grade science and ecology education. An empirical analysis of in-situ student map annotation activity is evaluated, compared, and contrasted across the two groups. A very strong argument may be made that the *Plant-Only Real-Virtual Group* resulted in more in-situ map annotation activity, than the *Plant-Only Virtual-Real Group*. Significant, strong results found the *Second Experience* superior to the *First Experience*, independent of *Environment, Real or Virtual*, on in-situ map annotation activity. Observed are interaction effects in all conditions, except for the *Plant Only Map Annotations* for *Group* by *Order*. The main contribution is the investigation of transfer of procedural in-situ knowledge from one field trip to the other, and the educational, learning, and teaching benefits such combined experiences offer in terms of multiplier effects. We present evidence of transfer in both directions, with evidence that the direction of the transfer of *Real* to *Virtual Environment* is much stronger. We conclude that the field trips should be used together to maximize learning activity.

High-fidelity, photorealistic, virtual-reality field trips are quickly becoming viable technology to use in school PC labs for enrichment, as price is rapidly approaching costs equal to existing multi-media systems. The main research question is whether or not such "true" virtual field trips can be educationally effective, and under what conditions.

Can virtual reality field trips provide meaningful learning and teaching experiences, and what critical design and execution parameters are required for success?

Furthermore, when is the virtual superior to the real?

When is the real superior to the virtual?

When and how can they work together to surpass the current state in practice?

A pilot study was conducted in May 2007. The opportunity to conduct an empirical comparison of the learning activity in-situ between a real field trip and the virtual-reality field trip was also taken. One of the goals of this study was to gather a variety of information required to inform educational software design, especially for child-centric human-computer interaction (HCI) user interfaced design. Additionally, the results from this research may be used to inform educational activities and decisions with respect to real and virtual field trips. The two most important design features of the new high-fidelity, scientifically accurate virtual environments are the level of realism and exploratory freedom they offer to the student. As such, quantitative data was gathered and analyzed on in-situ activity of the students to help understand the use, the value, and the benefit such tools present.

Data from the two environments was gathered, compared, and analyzed. The activity involved student free-will annotation of a 2D map of the field trip environment for anything that the students found to be personally meaningful, interesting, or salient. In this way, the mapping activity is similar to journaling but more objective and resistant to research interpretation, as it is discrete – they saw the Trillium and they recorded it —and used to create a count of recorded objects and events of personal meaning and value. It is our contention that such a method is superior to automatic data system logging so often used, because it reduces the noise and gives the researcher an explicit *student-created record* of events and objects that the student recorded as perceived, observed and meaningful. The data shows a very strong statistically significant order effect, thus proving that the second experience was more meaningful and interesting than the first, independent of the condition, real or virtual.

Thus, this study proved that repetition and practice, whether real or virtual, have significant impacts on perception, observation, and recording activity so essential for educational activities. Also found are very strong statistical trends that indicate that the *Real* and the *Real-Virtual* experiences are superior to the *Virtual* or *Virtual-Real* experiences. Last, there is strong statistical evidence of priming and transfer effects from the virtual to the real experience, and the real to virtual, which, once again, mainly reflects the order effect, independent of condition. There is a detailed description of the data and statistics provided to support these claims.

7.9.1 Research Design for Empirical Part of Pilot Study

7.9.1.1 Counterbalanced ANOVA with repeated measures

		Order	
		First Experience	*Second Experience*
Group	*Real-Virtual Group*	**Real Environment**	**Virtual Environment**
	Virtual-Real Group	**Virtual Environment**	**Real Environment**

Figure 34: Study One Counterbalanced Design

The design is a counterbalanced ANOVA with repeated measures on the map annotation activity for each student in each *Group*. Each *Group* of students experienced both environments in opposite order, the *Real Environment* and *Virtual Environment*. One group experienced the real field trip first then experienced the virtual field trip second. The other group experienced the virtual field trip first then experienced the real field trip second, as shown in Figure 34. Each subject acts as his / her own control (Siegel, 1956, p. 62), and allowed for a powerful comparison of the *Groups.*

All conditions were guide-facilitated by the same teacher, who was an educator and environmentalist, the coordinator of the Environmental Education Program from the Audubon Society of Western Pennsylvania. The field trip materials were a 2D map and a wildflower field guide book. The trails and the software had factual note-cards placed next to the plants of interest. These fact cards functioned as a form of augmentation in both the real environment and the virtual user interface. Both the real and the virtual environments had a perceptually identifiable trail, a natural affordance to suggest a route and a path to walk, but the virtual environment did not enforce path compliance. All field trips were based on the same curriculum, provided by the Audubon Society, the *Natural Communities* unit. The only difference was that, in the virtual field trip, the students could explore freely, independently, at-will, fly, swim, and travel off-trail. The data comparison methods consisted of measuring the student's in-situ activity of annotations to their paper maps in both the real and virtual environments. These annotations were proxies for personally meaningful and salient objects and events in each experience and resulted in an object count by type per student by environment. Unlike automatic computer logs, these logs represent objects and events that were personally meaningful.

7.9.2 Pilot Study Materials

7.9.2.1 Educational curriculum

For a full description of the educational curriculum, see the SEEE system above in Chapter 5. The educational curriculum was based on the fourth-grade *Natural Communities* lesson plan from the Audubon Society of Western Pennsylvania.

7.9.2.2 Pilot Study in-situ Assessment Instruments

The materials used consisted of a simple paper post-test and a 2D paper map. The parts of the post-test of concern for this report are the factual and conceptual components. The factual part required students to recall and name all of the plants, bushes, and trees they knew from memory, producing a total count per child. The conceptual part required students to work from recognition and label the parts of a flower, parts of a forest, and parts of a watershed, producing total correct count out of total available. The scoring consisted of the count of plants and the number of correct concepts out of the total.

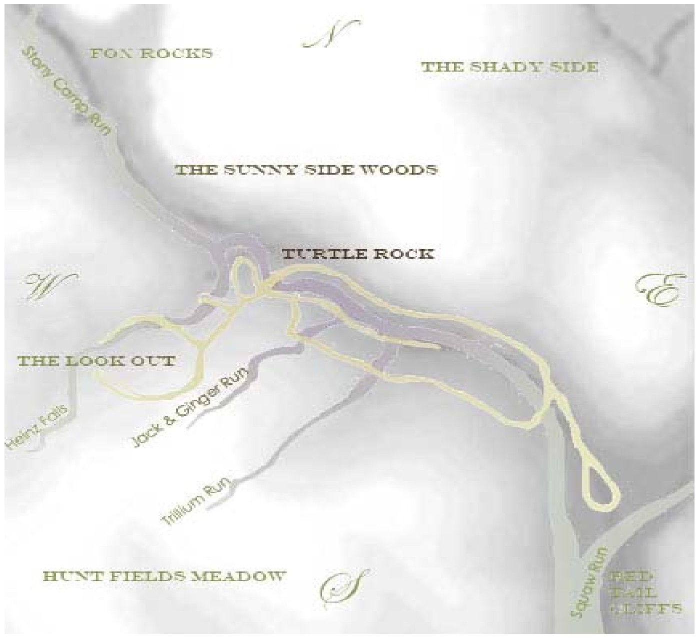


Figure 35: The 2D Map used to mark personally salient events and objects in-situ.

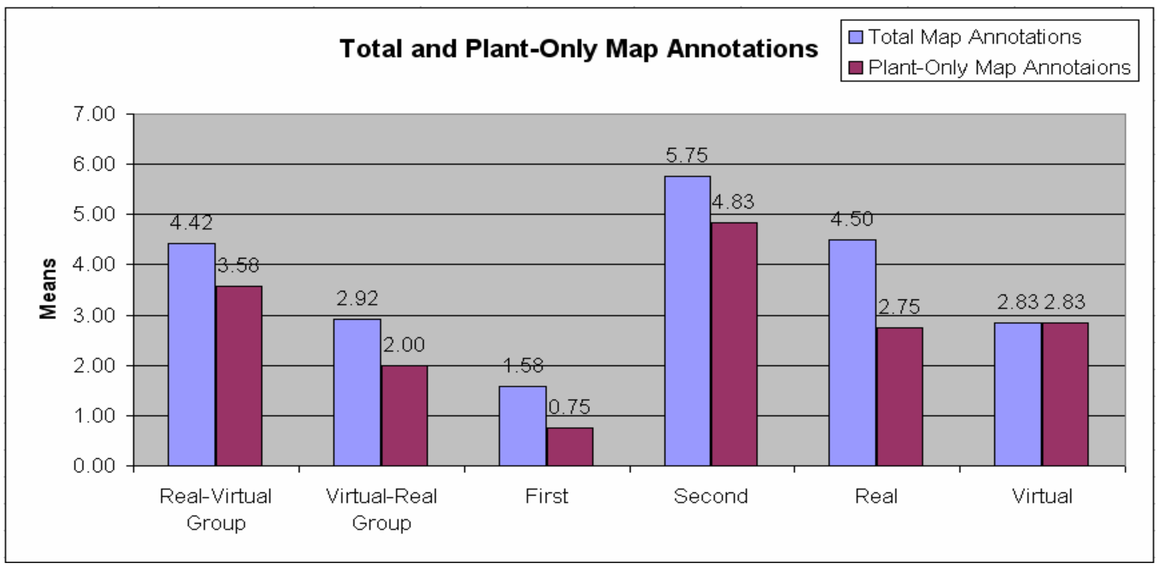
The in-test materials consisted of a 2D map, as shown in Figure 35., on which to annotate personally salient objects and events, and an Audubon Plant Field Guide book for look-up. Students used their own map in both the real and virtual field trips, and it was the same map matched to each individual student by student number. The map annotations per student provided a total count of the number of events and objects of personal significance (e.g., unexpected Salamander find or a Trillium flower), for each experience and for the total of both experiences, and by object and event type.

7.10. Pilot Study In-Situ Activity Analysis Results

7.10.1 Pilot Study In-situ Results for Map Annotations

The 2D Map annotations were important for two reasons. First, they provide a concrete record of in-situ exploration and personal significance. Second, the data set provided enough power to use parametric statistics for higher degrees of confidence in the interpretation of the in-situ activity and behavioral data. The summary of the findings are shown in Graph 3., where the statistics are reported and discussed in the following sections. The graphic shows trends in the data. The *Group* comparisons for *Total Map Annotations* and *Plant Only Map Annotations*, where the total count represents all objects and plants, in-curriculum or not that were marked on the map, and the plant-only represent the plants that were in both the curriculum and in the simulation of Trillium Trail. The *Order*, *First* or *Second* experience, is shown with an obvious spike for the *Second* experience, independent of environment or type of map annotation. Also shown on the graph is the experience condition as *Real* or *Virtual*, and the obvious spike for the *Total Map Annotations* in the *Real* environment.

Graph 3: Total and plant-only map annotations, by groups, experience order, and type



A simple Paired Samples t-Test was used to compare the categories as shown in Graph 3. There is no difference t(11) = 1.57, p = 0.145 between the *Total Map Annotations* in the *Real-Virtual Group* (M = 4.42, SD = 3.02) and the *Total Map Annotations* in the *Virtual-Real Group* (M = 2.92, SD = 3.31). However there is a difference t(11) = 2.45, p = 0.032 between the *Plant-Only Map Annotations* in the *Real-Virtual Group* (M = 3.58, SD = 3.02) and *Plant-Only Map Annotations* in the *Virtual-Real Group* (M = 2.00, SD = 2.25). There is a significant difference t(11) = - 4.894, p = 0.000 between the *First Total Map Annotations* (M = 1.58, SD = 2.54) and the *Second Total Map Annotations* (M = 5.75, SD = 2.17), and a significant difference t(11) = - 7.00, p = 0.000 between the *First Plant-*

Only Map Annotations (M = 0.75, SD = 1.42) and the *Second Plant only Map Annotations* (M = 4.8, SD = 2.12). There is no difference t(11) = 1.164, p = 0.269 between the *Total Map Annotations* for *Real* (M = 4.5, SD = 2.71) and *Total Map Annotations* for *Virtual* (M = 2.83, SD = 3.43) categories. An almost identical t(11) = -0.104, = 0.92 result is found for the *Plant-Only Map Annotations* for *Real* (M = 2.75, SD = 1.95) and *Plant-Only Map Annotations* for *Virtual* (M = 2.833, SD = 3.43) categories.

7.10.1.1 Pilot Study In-Situ Activity Group Comparisons

7.10.1.1.1 No difference in Total Map Annotations between groups

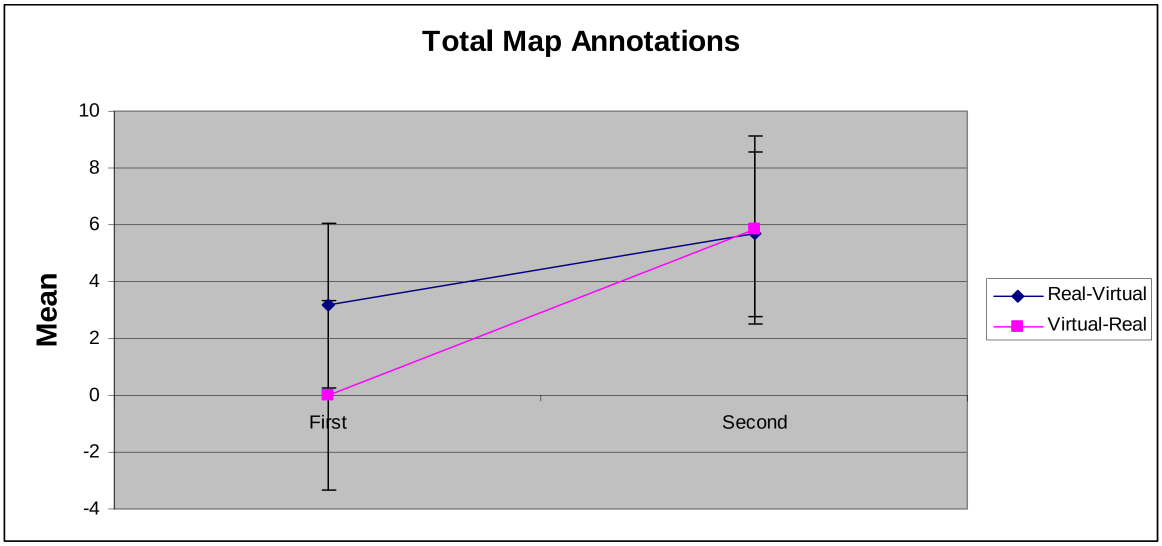
H_0: μ Total Map Annotations $_{\text{(Real-Virtual group)}}$ = μ Total Map Annotations $_{\text{(Virtual-Real group)}}$

The results of the Counterbalanced design with a Two-Factor ANOVA with repeated measures on one factor, show no difference in *Total Map Annotations* by *Real-Virtual Group* or *Virtual–Real Group*, F(1, 10) = 2.18, p = 0.17. Thus, there is no statistical evidence that the *Real-Virtual Group* in-situ activity (M = 4.42, SD = 2.90) is different from *Virtual-Real Group* in-situ activity (M = 2.92, SD = 3.32), for *Total Map Annotations*.

Table 5: Total Map Annotations by Group

Total Map Annotations	First	Second	Row Totals
Real-Virtual Group	n = 6 Mean = 3.17 *SD* = 2.86	n = 6 Mean = 5.67 *SD* = 2.58	n = 12 Mean = 4.42 *SD* = 2.90
Virtual-Real Group	n = 6 Mean = 0 *SD* = 0	n = 6 Mean = 5.84 *SD* = 1.94	n = 12 Mean = 2.92 *SD* = 3.32
Colum Totals	n = 12 Mean = 1.58 *SD* = 2.53	n = 12 Mean = 5.75 *SD* = 2.18	n = 24 Mean = 3.67 *SD* = 3.14

Graph 4: Total Map Annotations



7.10.1.1.2 No difference in Plant-Only Map Annotations between groups

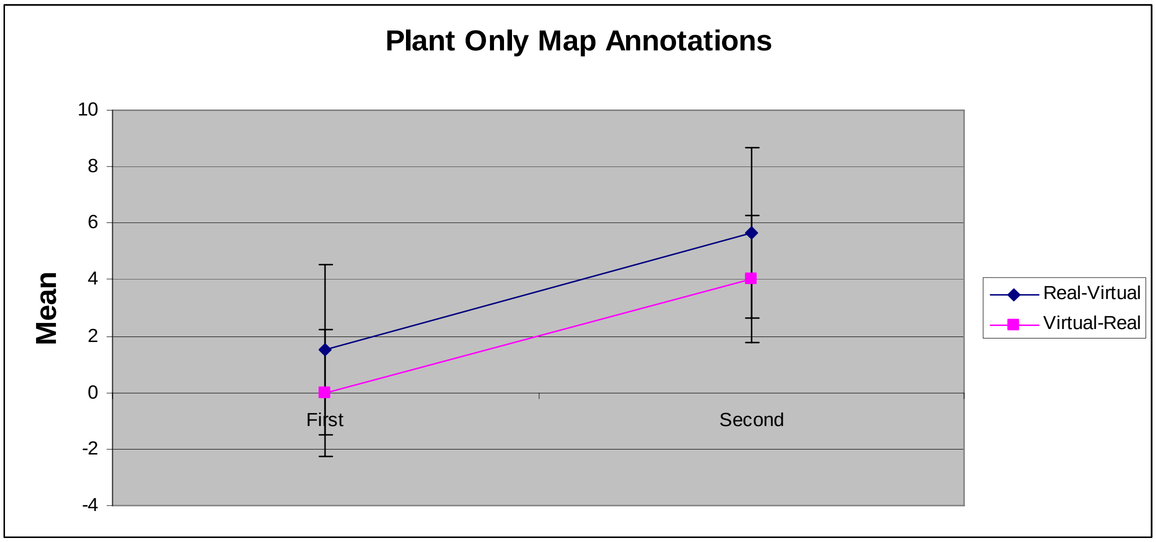
H_0: μ Plant-Only Map Annotations $_{\text{(Real-Virtual group)}}$ = μ Plant-Only Map Annotations $_{\text{(Virtual-Real group)}}$

The results indicate that there is no difference, but there is a strong trend towards differentiation in *Plant-Only Map Annotations* by *Real-Virtual Group* or *Virtual–Real Group*, $F(1, 10) = 4.37$, $p = 0.063$. However, the strong trend, the paired t-Test results, the ethnographic observations, and the graphical trend in Graph 3., warrant a deeper future analysis.

Table 6: Plant Only Map Annotations by Group

Plant-Only Map Annotations	First	Second	Row Totals
Real-Virtual Group	n = 6 Mean = 1.5 *SD* = 1.76	n = 6 Mean = 5.67 *SD* = 2.58	n = 12 Mean = 3.58 *SD* = 3.02
Virtual-Real Group	n = 6 Mean = 0 *SD* = 0	n = 6 Mean = 4 *SD* = 1.26	n = 12 Mean = 2 *SD* = 2.25
Colum Totals	n = 12 Mean = 0.75 *SD* = 1.42	n = 12 Mean = 4.83 *SD* = 2.12	n = 24 Mean = 2.79 *SD* = 2.73

Graph 5: Plant Only Map Annotations



7.10.1.1.3 Second experience more powerful, independent of group for both data sets of Total Map and Plant Only Map Annotations

H_1: μ Total Map Annotations $_{(First)}$ < μ Total Map Annotations $_{(Second)}$

H_1: μ Plant-Only Map Annotations $_{(First)}$ < μ Plant-Only Map Annotations $_{(Second)}$

The second experience independent of the environment resulted in higher annotation activities for both the *Total Map Annotations*, $F(1, 10) = 33.39$, $p = 0.000$, and for the *Plant Only Map Annotations*, $F(1, 10) = 44.66$, $p < 0.000$. The second *Total Map Annotation* mean (M = 5.75, SD = 2.18) was greater than the first (M = 1.58, SD, = 2.53) and so too was the second *Plant-Only Map Annotation* mean (M = 4.82, SD = 2.12) greater than the first (M = 0.75, SD = 1.42).

7.10.1.1.4 Interaction for Total Map Annotations but not for Plant Only Map Annotations

H_1: μ Total Map Annotations $_{(Real\text{-}Virtual\ group)}$ X μ Total Map Annotations $_{(Virtual\text{-}Real\ group)}$

H_0: μ Plant-Only Map Annotations $_{(Real\text{-}Virtual\ group)}$ X μ Plant-Only Map Annotations $_{(Virtual\text{-}Real\ group)}$

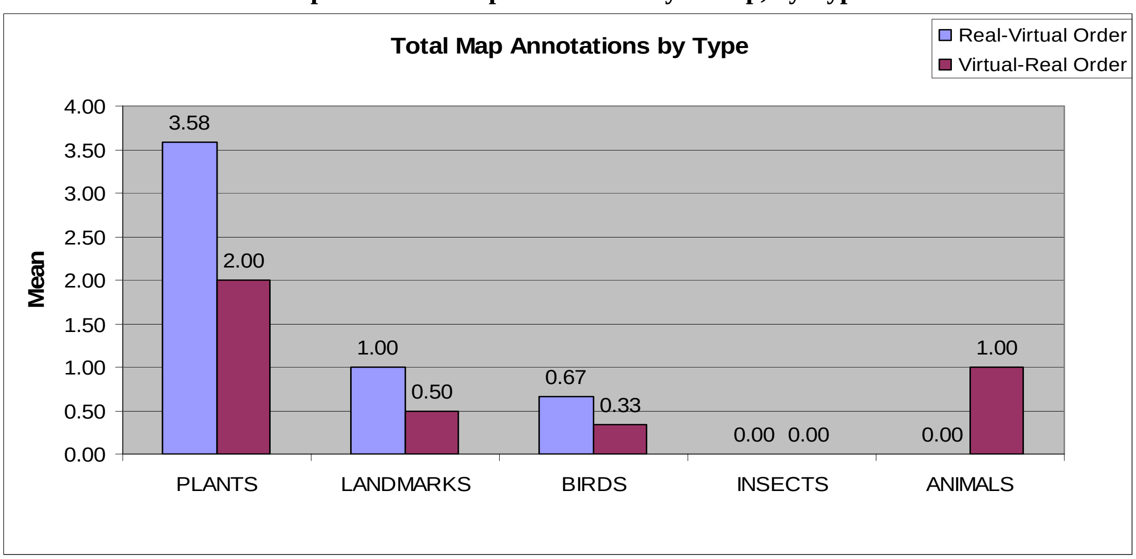
There was interaction in the *Total Map Annotations* data, $F(1, 10) = 5.34$, $p = 0.04$.

Of interest is the only relationship that showed no interaction. For *Plant-Only Annotations*, the ANOVA produced no evidence of interaction with a small effect, F(1, 10) = 0.02, p = 0.890. Thus, the order effect may be generalized across groups, *Real-Virtual* or *Virtual-Real*, as the second experience will always produce more in-situ behavior and activity when comparing in-curriculum and in-test-set information.

7.10.1.2 Pilot study in-situ classification of annotations by type

A close inspection and decomposition of the *Total Map Annotations* by object type shows differences in types of annotations (Graph 7). All map annotations, post-experience, were classified by the researcher into object types: *Plants*, *Landmarks*, *Birds*, *Insect*s, and *Animals*. Both groups saw birds, albeit different species, in the real field trip and annotated their maps; both groups saw insects but did not annotate their maps.

Graph 6: Total Map annotations by Group, by Type.



As show before with the Paired Samples t-Test, there is a significant difference t(11) = 2.45, p = 0.032 between the *Plant-Only Real-Virtual Group* (M = 3.58, SD = 3.02) and *Plant-Only Virtual-Real Group* (M = 2.00, SD = 2.25). Using a t-Test for independent samples, there is no differences between the number of annotations for *Landmarks t*(10)

= 1.17, *p* = 0.269, two-tailed, *Birds t*(10) = 0.85, *p* = 0.415, two-tailed, or *Insects* – no data – but a large difference between groups for *Animals t(*10) = infinity, *p* < 0.000, two-tailed. This was noteworthy, as one child was extremely fearful of spiders, and the other was playfully curious. The *Virtual-Real Group* experienced a salamander sighting, and thus resulted in a spike of recordings of *Animal* type, (Graph 7), in the *Real - Second* experience, thus "inflating" it relative to a situation that did not have such an event.

The ethnography would indicate that the spider sighting was meaningful, but evidently not to the individuals. However, the sighting of the salamander was a very big surprise to all of the children in the *Virtual-Real Group*, a classic episodic *"Teachable Moment,"* and indeed, the salamander was noted on all of their maps (100% marked the salamander on their maps) and classified as an *Animal* object type, the most likely cause for the interaction and noise in the data. What factors made the salamander sighting a significant *Salient Event* and the insect sightings insignificant are open to future research. The teacher treated both as moments to discus the curriculum, as viable and usable *"Teachable Moments,"* yet the children responded to each differently. Do we have a propensity to record, and thus actively try to remember only the positive experiences, but not the negative? Can such observations be used in user interface design? Can we intentionally design such *Salient Events* into user interfaces for educational virtual environments, and thus increase the likelihood of desirable information knowing activity?

The fact that there was a spike for *Animal* object type for the *Virtual-Real Group* and nothing recorded for the *Real-Virtual Group* partially explains the statistical similarity of the *Real Experience* and the *Virtual Experience*, previously reported – a cancelling out effect occurred. Thus, the question of *Real* vs. *Virtual* partially depends on the probability distributions of *Salient Events*, and that at this time is an unknown.

7.10.2 Pilot Study Evidence of the Transfer Effect

Is there transfer of skill from the virtual to the real for educational purposes, as measured in the activity? Many have claimed that preceding a real experience with a simulation or a virtual one will increase the knowledge and skill through transfer. The data in this study supports such claims.

H_1: μ Total Map Annotations $_{\text{(Real Environment First)}}$ < μ Total Map Annotations $_{\text{(Real Environment after Virtual)}}$
H_1: μ Plant Only Map Annotations $_{\text{(Real Environment First)}}$ < μ Plant Only Map Annotations $_{\text{(Real Environment after Virtual)}}$

For the *Total Map Annotations*, the t-Test statistic proves that the means are statistically significantly different, with statistics of, $t(10) = -1.89$, $p = 0.044$, one-tailed, thus rejecting the null hypothesis. For the *Plant-Only Annotations*, the t-Test statistic is stronger, showing, $t(10) = -2.82$, $p = 0.009$, one-tailed, thus, the *Virtual Experience* preceding the *Real* results in significantly better performance than the *Real Experience* alone, for in-situ activity critical for discovery-based learning.

However, is this not just the order effect? Are we not just comparing one group that had one experience, and the other group that had two experiences? Yes, we are, and that is the point - the virtual experience prior to the real experience effectively increased the in-situ activity.

If it is only an order effect, could not the opposite be true? Could we see transfer from the real experience to the virtual? In the past, such an analysis in mission control would not be tested, but for educational and learning applications, the question is valid and viable as a test. As measured in the activity of map annotation, the descriptive data from the *Virtual-Real Group Order* shows amount of annotation during the *First Experience* in the *Virtual Environment* ($M = 0.0$, $SD = 0$) to be lower than that in the *Virtual Environment* preceded by *Real Environment* ($M = 5.67$, $SD = 2.58$).

H_1: μ Total Map Annotations $_{\text{(Virtual Environment First)}}$ < μ Total Map Annotations $_{\text{(Virtual after Real)}}$
H_1: μ Plant Only Map Annotations $_{\text{(Virtual Environment)}}$ < μ Plant Only Map Annotations $_{\text{(Virtual after Real)}}$

For *Total Map Annotations* and for *Plant-Only Map Annotations*, a t-Test statistic proves that the means are statistically significantly different for both hypothesis, reporting statistics of, $t(10) = -5.38$, $p = 0.000$, one-tailed. Thus, the *Real-Virtual Group* activity is greater than the *Virtual* alone. The data shows the effect increases by 100% the annotation activity in-situ.

7.11. Pilot Study Discussion of Virtual Enhancing Real

The evidence showed that the virtual field trip used to prepare students prior to a real field trip results in gains of 69% in desirable learning activity such as map annotation. It also showed that the real field trip, followed by a virtual field trip, results in gains of 100% on the desired behavior. The *Real-Virtual Group* order has stronger transfer effects than the *Virtual-Real Group* order. Thus, as these results suggest, the total multiplier effect for structuring the educational and learning activity of a real field trip with learning enhancing virtual reality field trips can be maximized, by first offering a virtual reality field trip, then the real field trip, followed by the virtual reality field trip.

This empirical analysis, of the Real and Virtual Trillium Trail on the discovery based learning activity of annotating a map in-situ, has yielded many important observations and conclusions. However, it has also raised important new questions. The first interesting question deals with the fact that the study had homogeneous user profiles, as is typical for block samples used to minimize variance and noise. We would expect quite a difference in results with a different user profile, such as a homogeneous group that did not like nature or computers. Using block design is an accepted practice in software product design, as we attempt to design the software to meet the needs of each profile or market segment. The analogy to this approach is like offering many different sizes of blue jeans for people to find the "right fit." It would be ridiculous to offer only one blue jean size for all people. The ideal, of course, is to have custom-made jeans, with a perfect fit to body dimensions. Software design is currently moving in such directions, with dynamic adaptation, personalization services, and an interactive triage of the user profile in-situ, as people do change over time; thus is software "fit" in terms of high degrees of personalization and adaptation for ideal usability (Brusilovsky, 2002).

The next point to discuss is the post-test. While the results are impressively the same, upon closer scrutiny, they are not really that impressive. This was a homogeneous group, one that prepared for the real field trip all year. The test was based on very simple facts and concepts and, as with all standardized tests, constrained to the curriculum studied. One would expect that the students would do well. The tests did require factual recall from memory of flowers, plants, bushes, and trees from both groups in the separate *Environments, Real* or *Virtual*. This is not to claim that the two experiences were the same; as we saw with the *"Salamander Effect,"* only the test results, constrained by what the tests measured, are the same. This is actually a very important note for future research, as much of the in-situ activity was a record of personal, meaningful, salient episodic events and discoveries. The future challenge will be to make meaningful tests, if tests are needed at all, for such dynamic discovery-based environments.

Now, we turn to the most important and interesting part of the results of this study: the activity in context, both in and out of curriculum, and what it tells us about the learning opportunities of such *Environments* and *Order* of experience. As such, the in- curriculum material is represented by the data in the *Plant-Only Map Annotations*, and the out-of-curriculum material is represented by the data in the *Total Map Annotations*. The data showed interaction effects for the *Total Map Annotations*, but not for the *Plant-Only Map Annotations*. Why? There are two likely explanations. First, as previously explained, the *"Salamander Effect"* was only recorded in the *Real Environment* and statistically analyzed under the *Total Map Annotations* data set, so there are at some level of probability events that occur only in the real environment and cannot be planned for or forecast. These types of *Salient Events* are sometimes the most remembered, and since they can act like a powerful episodic anchor for the entire trip, they are critical events for success. The most important empirical finding is that the *Real-Virtual Group* strongly suggests the superior combination and that both *Groups* showed that the *Second Experience* increases the in-situ activity significantly. Thus, the second experience, real or virtual, will increase activity, significantly and substantially. This result should be generalized to the population representative of the user profile.

The *"transfer effects,"* independent of the order of the combined *Environments*, show a powerful increase in activity from virtual to real, of close to 70%, and from real to virtual at 100%. These results together suggest a new approach, one not possible in life-critical training simulators: that of offering the real field trip first. The most important direction to investigate is how virtual reality can be used to augment and surpass the current state of discovery-based teaching today — not to replace it.

The ethnographic and empirical conclusions for the pilot study indicate that if only one field trip can occur, choose the real, as it has more event-opportunity, and learning-activity. The virtual should not replace the real, if the real is available. It is important to note that the *Virtual-Real Group* did not annotate their maps at all in their first experience and that only in the real field trip was there a salient episodic event, that of the salamander sighting, the *"Salamander Effect."* The test data between the real field trip and the virtual field trip for in curriculum set information was statistically identical, but this does not indicate that the experiences or even all information discovered or learned are the same. Number of plant facts equaled or exceed teachers learning expectations for both the real and the virtual trips, suggesting that the virtual field trip can be used, if sensitively, for educational purposes, especially if the goals are to prime a student for a real world experience and transfer of knowledge and skill. Additionally, following a real field trip with a virtual will also offer advantages to reinforce the learning activity in the real and offer potential collaboration activities. Independent of real or virtual *Environments*, repeating activity will improve perception, observation, and annotation activity, as was strongly proven with the main effect, of *Order*. However the *Real-Virtual Order* is preferred to the *Virtual-Real Order*, when all of the information is considered. The strong evidence of transfer effects on in-situ activity suggests that activities should be combined for improved richness and increased learning opportunity. The main contribution of this study is a new frame of reference when considering virtual reality field trips; it is to use the real and virtual learning experience together for maximum impact.

8. MAIN STUDY: DETAILED EMPIRICAL INVESTIGATION INTO THE EFFECTS OF HCI SALIENCE DESIGN PARAMETERS ON EXPLORATION, INQUIRY, EMOTIONS, AND LEARNING

This chapter is the detailed empirical investigation into the HCI salience design parameters of Visual Fidelity and Navigational Freedom on Exploration, Inquiry, Emotions, and Learning, and represents the main empirical analysis of the thesis, which here examines the effects of Visual Fidelity and Navigational Freedom, two key design parameters in this study, on intrinsically motivated learning. It does so by measuring across the salience dimensions of high and low values in Visual Fidelity ranging from photo-realism to cartoon-like visual representations; and in Navigational Freedom ranging from infinite degrees of movement choice to path-restricted movement. Furthermore, an unexpected gender effect appears to be interacting across all conditions and so a data exploration on gender was added to the evaluation. Additionally, the results of the subjective attitudinal survey are reported and interpreted.

8.1. Main Study Research Design

The main study is a quantitative, empirical investigation into the design parameters of *Visual Fidelity* and *Navigational Freedom* of a SEEE. The intention is to structure a planned orthogonal quantitative experiment that will produce data that can fit a set of regression equations with the highest degree of confidence possible (Glass & Hopkins, 1996, pp. 152-188). The SEEE software was intentionally designed and developed to support the constraints imposed by a planned orthogonal contrast (POC), as a way to design the most powerful tests of mean differences (Glass & Hopkins, 1996, pp. 482-524). “The POC employs a contrast-based type-I error rate α. Each part is associated with a contrast. Thus, the j-1 possible orthogonal contrasts contain unique, non-overlapping information. In balanced (equal n) designs, the two contrasts ψ and ψ' are orthogonal when the products of the corresponding contrast coefficients sum to zero” (p. 459).

Before any regressions are run, we will examine the independent factors – *Visual Fidelity* and *Navigational Freedom* - in a focused 2x2 ANOVA. The design is used to determine independence (or the amount of interaction between the independent factors) and the kind of influence they have on the dependent variables – *Knowledge Gained, Salient Events, Fact Inquiry, Time in System* and *Emotions*. The research design for the main study is an in-depth quantitative analysis. The SEEE software, the research design, and the research plan, make such a detailed statistical evaluation possible.

The virtual environment (VE), user interface (UI) and emotions (EMOT), maybe thought of as design parameters that cause inquiry, exploration, positive emotions, learning, and a desire to create. The main research thrust is to investigate the degree of impact these factors of *Visual Fidelity* and *Navigational Freedom* have on the outcome variables of interest. Could we quantitatively fit the following types of predictive equations?

$$\boxed{\mathbf{\Delta Knowledge\ Gained} = \alpha + \beta_1 (\mathbf{VE}) + \beta_2 (\mathbf{UI}) + \beta_3 (\mathbf{EMOT}) + \varepsilon}$$

Certainly, if a child is interested in the subject matter, he or she will be more inclined to learn. But, surely there are times, when new interests are spiked by a perception or event in the environment. How does this happen? Can it be harnessed? The second point is the child's pre-existing knowledge of that subject, and how that knowledge may improve perception. How does one teach another to see, for you can only see what you know? Next, the environment with events will entice, intrigue, excite, and so may be used as access points for inquiry. What if they are not? Can the system intentionally entice? Last, the child's emotional reactions to the environment and events are viewed as critical design features, because the more the child enjoys the experience, the more likely they will be to continue, "flow" (Csikszentmihalyi, 1991), and the more time learning, will result in more information learned (Carroll, 1963). Time, not just time spent on completing some task, but time the child self-elects to spend on the task is critical. Does it follow that the more time they spend the more they will learn? How to design for these goals?

8.1.1 Framed in Two Dimensions

The research design for the main study is a ***planed orthogonal contrast (POC) design*** using a 2x2 ANOVA. The virtual environment (VE) has the factors of: *Visual Fidelity* and *Navigation Freedom*. The system is deployed in the form of a desktop PC virtual environment with standard input devices – mouse and keyboard – and standard output devices – screen – and soft elements of annotation – a tool-tip-like fact cards associated with objects and audio sprites. The user interface (UI) may be defined as the combination of the input and output devices, soft tools, search, navigation, annotation, and augmentation elements. All SEEE UI elements will be held constant across all conditions, thus permitting an empirical comparison along the two modified dimension of *Visual Fidelity* and *Navigational Freedom*. This design assures high internal validity for both the system and the statistics. The curriculum embedded in the system was held constant as well. Other important dimensions for this research are in emotional ranges. Examples of emotional ranges are in the dimensions of boredom to excitement, fear to safety, disgust to awe and wonder just to name a few. This research attempts to hold constant, and at a high level, excitement, safety, awe and wonder, for the child's emotional engagement and experience. The virtual environment is a data simulation consisting of 3D CGI wire frame models of terrain, plants, and texture maps. The geometrical structure will not change, only the fidelity of the object's textures, to produce the two high and low conditions, or values, on the *Visual Fidelity* salience scale.

Visual Fidelity was selected as a factor, because of three main reasons. First, the defining criterion of virtual environments is the approximation to photo-realistic reality, and therefore *Visual Fidelity* is a critical feature of all virtual environments, especially for the creation of presence. Second, many educational applications use cartoon-like quality images or images that are based on fantasy and thus the image is the artist's interpretation of reality – misconceptions abound? Third, many hand-held devices, such as the NintendoDX, or collaborative networked platforms such as SecondLife.com make experiencing virtual environments anywhere and anytime possible – on school buses, in cars, on the playground – but the graphics on these portable and networked devices are of lower quality than those found on X-Boxs, Play-Stations or high end desktop PCs. The *Low Visual Fidelity* implementation is the cartoon-like quality image, with a salience score of 68. The *High Visual Fidelity* implementation is a photo-realistic image quality with a salience score of 105.

Navigational Freedom was selected as a proxy for free-will and free-choice in exploration and inquiry. Exploration requires navigation to facilitate knowledge acquisition. The child cannot search for that which they do not know. However, they can explore and in the process discover things of interest that they did not know of before. The entire purpose of SEEE is to support the child in independent acts of exploration and discovery. Navigation research in virtual reality is relatively new in how it influences learning. Recent evidence shows the advantage of scaffolding and restricted navigation for some procedural based learning in virtual reality systems (Roussou, Oliver, and Slater, 2006). We know that for some knowledge such as procedural, tactile, or process-based knowledge, constrained navigation is desirable. Secondly, traditional educational applications constrain navigation, intentionally, as the students are guided, such as might be needed for tutoring Algebra (Koedinger and Anderson, 1997) or C programming (Brusilovsky and Sosnovsky, 2005). Thus, the system will contrast *Low Navigational Freedom* with a salience score of 96, and the *High Navigational Freedom* has the salience score of 147. This factor may ultimately prove to be a design choice, based on exogenous factors and learning goals.

8.1.2 Main Study Two-way ANOVA Research Design

Visual Fidelity

Navigational Freedom	*Low Visual Fidelity*	*High Visual Fidelity*
High Navigational Freedom	**Group LFHN**	**Group HFHN**
Low Navigational Freedom	**Group LFLN**	**Group HFLN**

Figure 36: A 2x2 ANOVA design of the two main factors.

8.1.3 Main Study Questions

I. Do difference levels of *Visual Fidelity*, have an impact on:

- *Knowledge Gained* – difference between the pre-test and post-test as a percent gain.
- *Salient Events* – number of objects or sprites investigated.
- *Fact Inquiry* – count per object number of facts selected.
- *Time in System* – voluntary time elected to stay and play.

II. Do difference levels of *Navigational Freedom*, have an impact on:

- *Knowledge Gained* – difference between the pre-test and post-test as a percent gain.
- *Salient Events* – number of objects or sprites investigated.
- *Fact Inquiry* – count per object number of facts selected.
- *Time in System* – voluntary time elected to stay and play.

III. Is there interaction between the factors of *Visual Fidelity* and *Navigational Freedom*:

- *Knowledge Gained* – difference between the pre-test and post-test as a percent gain.
- *Salient Events* – number of objects or sprites investigated.
- *Fact Inquiry* – count per object number of facts selected.
- *Time in System* – voluntary time elected to stay and play.

8.2. Main Study Empirical Analysis

8.2.1 Tests for Independence

Since this is ***a planned orthogonal contrast (POC) used to increase the power –*** a 2x2 ANOVA design tests the results for independence of the SEEE variables. The ideal study and research design would produce properties of estimators of parameters that are unbiased, efficient, and consistent, with distributions that are normally distributed and variances approaching zero.

8.2.2 Hypotheses for the 2x2 ANOVA

8.2.2.1 Hypotheses for *Knowledge Gain*

H_0 1: μ Knowledge Gain $_{(HF)}$ = μ Knowledge Gain $_{(LF)}$
H_a 1: μ Knowledge Gain $_{(HF)}$ =/= μ Knowledge Gain $_{(LF)}$

H_0 2: μ Knowledge Gain $_{(HN)}$ = μ Knowledge Gain $_{(LN)}$
H_a 2: μ Knowledge Gain $_{(HN)}$ =/= μ Knowledge Gain $_{(LN)}$

H_0 3: No Interaction on Knowledge Gain: Visual Fidelity X Navigational Freedom
H_a 3: Interaction on Knowledge Gain: Visual Fidelity X Navigational Freedom

8.2.2.2 Hypotheses for *Salient Events*

H_0 1: μ Salient Events $_{(HF)}$ = μ Salient Events $_{(LF)}$
H_a 1: μ Salient Events $_{(HF)}$ =/= μ Salient Events $_{(LF)}$

H_0 2: μ Salient Events $_{(HN)}$ = μ Salient Events $_{(LN)}$
H_a 2: μ Salient Events $_{(HN)}$ =/= μ Salient Events $_{(LN)}$

H_0 3: No Interaction on Salient Events: Visual Fidelity X Navigational Freedom
H_0 3: Interaction on Salient Events: Visual Fidelity X Navigational Freedom

8.2.2.3 Hypotheses for *Fact Inquiry*

H_0 1: μ Fact Inquiry $_{(HF)}$ = μ Fact Inquiry $_{(LF)}$
H_a 1: μ Fact Inquiry $_{(HF)}$ =/= μ Fact Inquiry $_{(LF)}$

H_0 2: μ Fact Inquiry $_{(HN)}$ = μ Fact Inquiry $_{(LN)}$
H_a 2: μ Fact Inquiry $_{(HN)}$ =/= μ Fact Inquiry $_{(LN)}$

H_0 3: No Interaction on Fact Inquiry: Visual Fidelity X Navigational Freedom
H_a 3: Interaction on Fact Inquiry: Visual Fidelity X Navigational Freedom

8.2.2.4 Hypotheses for *Time in System*

H_0 1: μ Time in System $_{(HF)}$ = μ Time in System $_{(LF)}$
H_a 1: μ Time in System $_{(HF)}$ =/= μ Time in System $_{(LF)}$

H_0 2: μ Time in System $_{(HN)}$ = μ Time in System $_{(LN)}$
H_a 2: μ Time in System $_{(HN)}$ =/= μ Time in System $_{(LN)}$

H_0 3: No Interaction on Time in System: Visual Fidelity X Navigational Freedom
H_a 3: Interaction on Time in System: Visual Fidelity X Navigational Freedom

8.2.3 Independent Variables for the Main Study 2x2 ANOVA

The independent variables in the Main Study are *Visual Fidelity and Navigational Freedom.*

- **Visual Fidelity** is an independent variable, and one of the main factors in the 2x2 ANOVA design. It will have two levels: *Low* (LF) and *High* (HF).
- **Navigational Freedom** is an independent variable, and it is other main factor in the 2x2 ANOVA design. It will have two levels: *Low* (LN) and *High* (HN).

8.2.4 Dependent Variables for the 2x2 ANOVA

The depended variables are *Knowledge Gained, Salient Events, Fact Inquiry*, and *Time in System.*

8.2.4.1 Knowledge Gain

The knowledge gained in the experiences is a dependent variable. This is a traditional measurement of facts, concepts and values as measured as a percentage change between the post-test scores and the pre-test scores (see Appendix G).

- **Definition:** This is the pre-test and the post-test difference as a percent.
  Knowledge Gain = [(post-test score – pre-test score)/ post-test score]
- **Rationale:** To measure the amount of facts, concepts and values that are affected by the experience with the SEEE software, or the amount of learning that resulted from experiencing the system.
- **Range:** [0% – 100%]
- **Expectation:** It is expected that many of the facts will be known in the pre-test for facts, but few of the concepts, especially the ones that deal with context and form and function. The biggest shifts may be in the values.

8.2.4.2 Salient Events

A system formed *Salient Event* creates a *Teachable Moment.* Any object that results in the student stopping to read or listen is counted as a *Salient Event*. Effectively, this count is when the student decided to stop navigation, stop exploration, and to initiate an act of inquiry. A student may see a flower's fact card and walk towards it and stop. A student may see a sprite and walk over to it, stand inside it, and listen to the audio recording. If the student has a flower fact card in view, but walks by the card, it is not counted. If she has a sprite in view and walks by or through it, it is not counted. Only events where the student stops are counted. The children in the training session will be shown this so they expect only plants to respond.

- Number of Objects Selected
    - There is some number in a given view.
    - Student selects which to investigate or not.
    - If a card, then the system responds with the **name** and **other facts**.
    - If a sprite, then the system automatically plays the audio recording of a **concept.**
- **Definition:** A count or number of plant objects and audio recordings that the child selects to investigate.
- **Rationale:** A proxy for ***exploration*** that can be correlated to the other variables, of most interest of which is the broad ***context-based*** and ***conceptual-classified*** post-test questions (e.g., "How do you identify a Trillium?", "What is the name of the plant that has fruit, that the turtles likes to eat?", (Appendix G).
- **Range:** [0 to 100] objects. Each object will have the same weight.

Expectation: The framing of the problem and situation is completely under the student's control. The only instructions are to go and explore as much or as little as desired.

8.2.4.3 Fact Inquiry

When the child clicks on an object's fact card, the UI will respond with the fact hierarchy of cards. Each fact card with data and information is an instance of *Fact Inquiry*, but not the cards poising questions. The children will be shown this in the training session, so they will know what to expect. Each click on each fact card is an interaction activity that will be recorded as on instance of *Fact Inquiry*.

- Number of Facts Selected per Object.
  - There is some number of facts in the set per object.
- **Definition:** A count or number of plant object facts the child selects. The fact hierarchy is automatically displayed after the child selects the card. It is an instant UI response of the action of selecting the object. (For example, it is the equivalent to the child in the real world, turning the fact card over to see the details.)
- **Rationale:** A proxy for ***deep interest in the object*** that can be correlated to the output variables, of most interest of which is the detailed ***object-facts*** in the post-test questions (e.g., “How do you identify a Trillium?”, “What is the name of the plant that has fruit, that the turtles likes to eat?”, (Appendix G).
- **Range:** [1- 6] facts per object. This is flower/plant or object dependent. Each fact will have the same weight. Assigning weights may be important in the future, but for this experiment all facts will be treated the same. The total facts in the system are 240.
- **Expectation:** It is expected that with the higher levels of visual fidelity, more facts will be selected per object. It is also expected that same number of facts per object will be inquired statistically independent of the condition. There may be individual differences and correlations with user profile. It is expected that the objects that were independently selected in the post-task activity will have more facts inquired.

8.2.4.4 Time in System

- **Definition:** Minutes the child chooses to stay in the system is the total time.
- **Rationale:** A proxy for ***enjoyment*** that can be correlated to the output variables.
- **Range:** [0 to 60] minutes. Students may stop at will, or continue for the maximum allowed time.
- **Expectation:** More students will on average spend more time in the HFHN system than in any of the other conditions. This finding would be consistent with previous work and would not be surprising.

8.3. Main Study Experiment

8.3.1 Population

The volunteer sample (*N* = 64) was drawn from urban, suburban, and rural, public, private and home-school populations, located in and outside of Pittsburgh, PA. All participants were volunteers, as the study was required to protect the rights of human subjects in research as is legally required by Federal Regulations. The population is diverse, but biased towards an upper socioeconomic profile. As such, the volunteers were all interested in computers, video games, nature, and art. The sample was restricted to third, fourth and fifth grade students, and used the legal definition for those grades. Recruitment occurred between March 2008 and June 2008 through schools, PTO mail lists, and individual referrals. Additionally, demonstrations of the system to the public at several Earth Day events at nature reserves and a Mother's Day event at a botanical garden resulted in the recruitment of student volunteers. Three volunteers were refused, as one was in sixth grade, one student was dyslexic, and one was autistic.

8.3.2 The Sample

Random assignment to one of the four conditions was done to insure internal validity. The volunteer was assigned a number by using a random number generator without replacement on digits from 1-64, and then pre-assigned to one of the four conditions prior to the time of the study. A correlation coefficient between volunteer order number and random placement number is -0.05. The researcher gave the same pre-experience demographic survey from the pilot study to all volunteers prior to the main study. Of interest was a user profile, age, grade, self-rank of PC computer expertise, and self-ranking of enjoyment of nature. To verify that the four groups were homogeneous prior to the running of the study, a One-way ANOVA was run on the data to compare the variables of *Grade in School,* ($M = 4.03$), $F(3, 61) = 0.5199$, $p = 0.67$, *Gender* ($M = 0.625$), $F(3, 61) = 1.2392$, $p = 0.303$, *and Pre-test Score* ($M = 21.59$), $F(3, 61) = 0.9117$, $p = 0.4407$. All four groups were found to be statistically identical.

8.3.3 Materials

8.3.3.1 Curriculum

The educational content came from the Audubon Society of Western Pennsylvania's *Natural Communities* curriculum for the fourth grade (Audubon, 2005), for more detail see the curriculum description in Chapter 5.

8.3.3.2 Main study demographic user profile survey

Prior to the experience, a demographic and user profile interview and survey was administered by the researcher (Appendix G).

8.3.3.3 Main study pre- and post-tests

The pre- and post-tests were pure recall for facts and concepts. A few questions gathered beliefs and values as well as a drawing of a "Forest Ecosystem" (Appendix G). The tests were identical in content and layout. They were administered by the researcher prior to the system condition experienced and immediately following the experience with the software, to test for any difference in pre- to post-test scores based on the experience with the software.

8.3.3.4 Main study post-experience interview and survey

Much like the one from the pilot study, the main study used a post-experience interview, survey and microworld study. The objective was to find subjective, emotional, affective, aesthetic and attitudes that are self-reported (Appendix G), across all four conditions and to explore the data for correlations with the quantitative test data, in-situ activity data, and the pre-experience user profile data. The data was gathered along the exact same dimensions as in the pilot test, but as the students only experienced one condition, they could not compare or contrast conditions.

8.3.3.5 The POC system

The SEEE system was modified along the two main factorial dimensions, that of *Visual Fidelity* and that of *Navigational Freedom*, so that the impact of each could be statistically measured.

8.3.3.5.1 The four system conditions

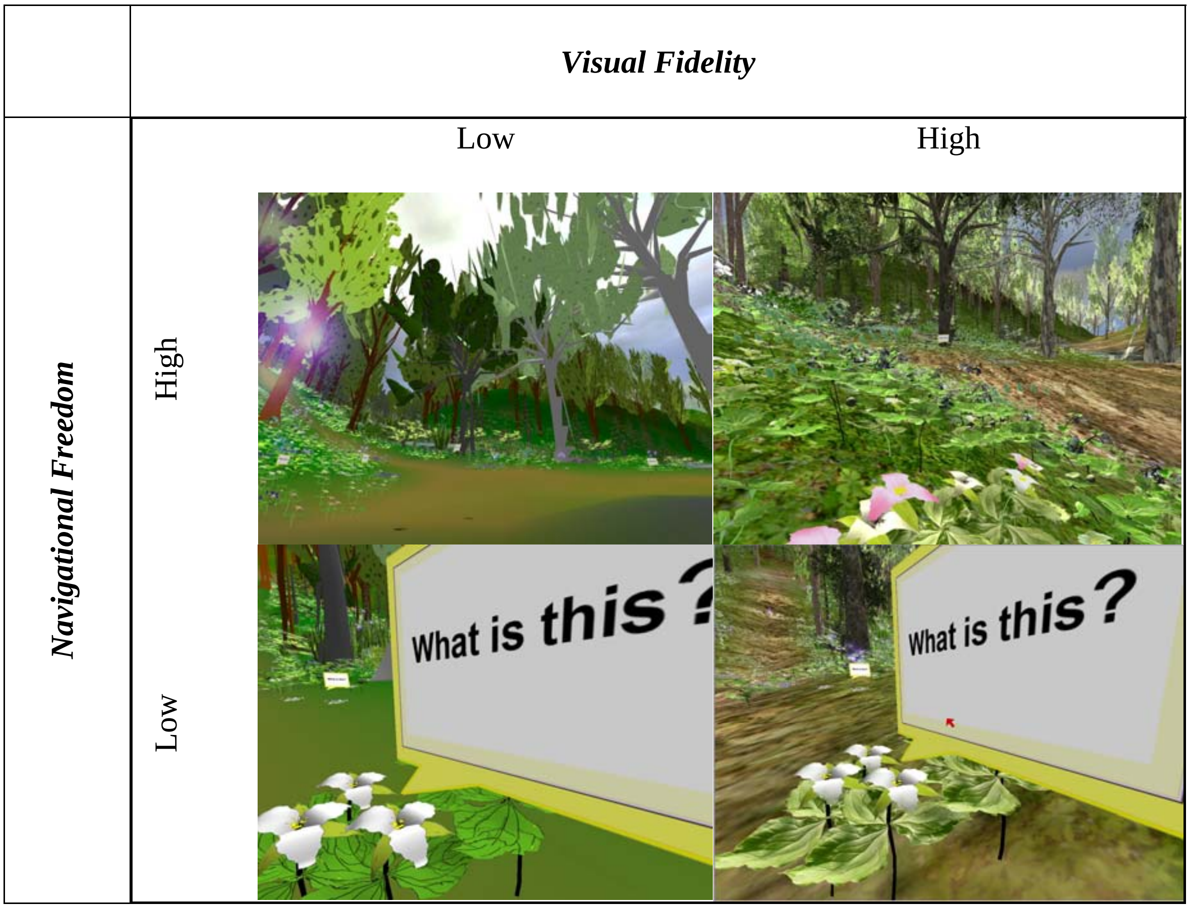


Figure 37: The SEEE four POC system conditions.

By combining the design options in each dimension, truly orthogonal system states are created; one state for each of the four conditions in both the system and the statistical design. This is required for internal system and internal statistical design validity. We are not comparing four different systems; we are comparing the same system with four different internal system attribute settings.

The four test conditions of the SEEE system:

1. SEEE *High Visual Fidelity* and *High Navigational Freedom* (HFHN)
2. SEEE *High Visual Fidelity* and *Low Navigational Freedom* (HFLN)
3. SEEE *Low Visual Fidelity* and *High Navigational Freedom* (LFHN)
4. SEEE *Low Visual Fidelity* and *Low Navigational Freedom* (LFLN)

8.3.3.5.2 High Visual Fidelity and Low Visual Fidelity conditions

Figure 38: The left image represents the *High Visual Fidelity* condition, and the right image represents the *Low Visual Fidelity* condition

The *Low Visual Fidelity* model was identical to the *High Visual Fidelity* 3D computer graphic model. It had the same terrain, identical plants, all objects in the same location, and the same identical UI in the same locations. The *Low Visual Fidelity* was created by using cartoonistic images as texture images, while retaining the critical salient attributes of the leaf structure for identification purposes. The real photographs were used as texture images in the *High Visual Fidelity* condition for the photorealistic image quality. This way, we were able to create a cartoon version that was in every way identical to the photorealistic version, save for the quality of the texture maps.

8.3.3.5.3 High Navigational Freedom and Low Navigational Freedom conditions

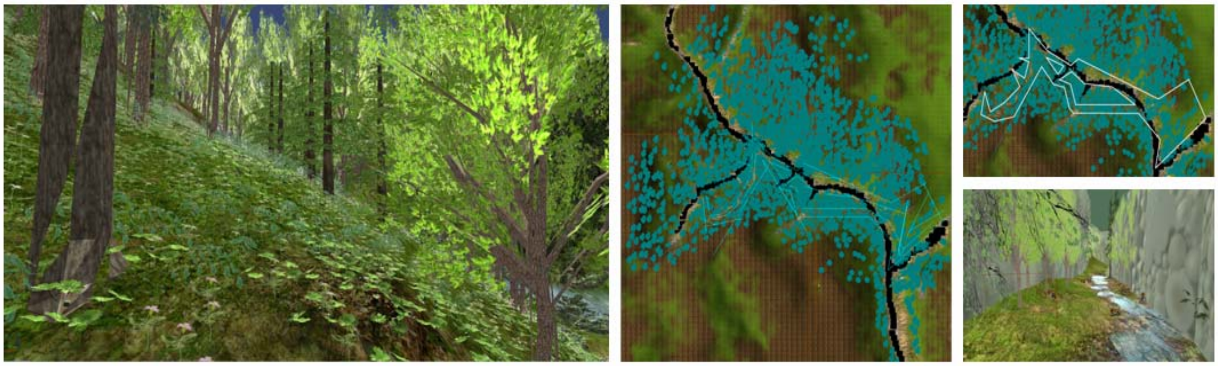


Figure 39: The High Navigational Freedom and Low Navigational Freedom condition. Invisible walls, far right images, restrict movement from the path, thus creating a Low Navigational Freedom condition from the High Navigational Freedom condition, far left and center images.

The *Low Navigational Freedom* condition was a modification of the *High Navigational Freedom* condition system. It simply restricted students' movement to the path by using invisible walls (Figure 39.). These walls can be visible in the editor (Figure 39) but invisible in the executable. Thus, the same model can be modified to restrict movement. There is still some choice, but it not completely free, as in the high navigation model.

8.3.4 Methods

8.3.5 Process for the Main Study

User Profile Demographic Survey	**Pre-Test** On Facts, Concepts, Values and a Drawing	**Experimental Condition**	**Post-Test** on Facts, Concepts, Values and a Drawing	**Microworld Study**	**Post-Experience Attitude** Survey on Emotions and Impressions
		LFHN **HFHN**			
		LFLN **HFLN**			

Figure 40: Main study process

8.3.6 Procedure

- After IRB consent process completed.
- An equal number of 16 subjects were assigned to each condition based on random number assignment.
- All subjects received a pre-test.
- Subjects received a scripted tutorial and up to fifteen minutes of training time on the system.
- All subjects received the same instructions, “Go and explore and inquire at will and stop at anytime.”
- All instructions were scripted and held constant across all conditions.
- Subjects could continue at will or stop at any time.
- All activity was video- and audio-recorded and logged in lab notebook.
- Once a subject selected to stop, he / she received an immediate post-test, identical to the pre-test.
- A follow-up Microworld activity was scheduled to occur at their convenience, and about one week later
- An attitudinal interview and survey was administered.

8.3.7 Assessment instruments

The materials consisted of a simple paper pre-experience demographic survey, and pre- and post-tests, administered by the researcher. The test content, presentation, and grading rubric key were identical for the pre- and post-test. Facts, concepts, values, and a drawing were collected (Appendix G). A notebook and a digital video- and audio-recording device were used to capture user activity in-situ. The automatic computer logs created by Unreal (UnReal Technology, 2008) have proven to be too nosy and record false positives. With the video recordings, an audit was allowed and correct recording of all *Salient Events* and *Fact Inquiry* activity was possible.

8.4. A Two Factor Analysis of the Variance Design Results

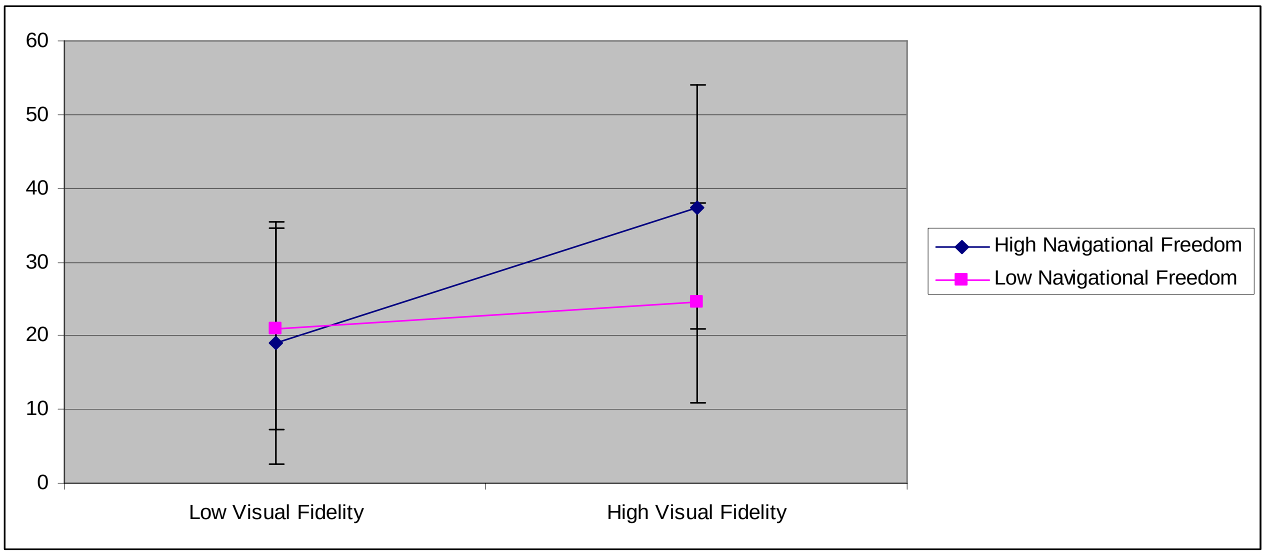
8.4.1 Difference in Pre-Post Tests *Knowledge Gain*

How did *Visual Fidelity* and *Navigational Freedom* impact knowledge gain, as measured by the difference between the post-test and pre-test as a percent? A Two-way ANOVA was used to test main effects and interaction effects, for all variables under investigation.

Table 7: Main Study Contingency Table Knowledge Gain

	Low Visual Fidelity	High Visual Fidelity	Row Totals
High Navigational Freedom	n = 16 Mean =19.05 *SD* = 13.8	n = 16 Mean =37.44 *SD* = 13.88	n = 32 Mean = 28.24 *SD* = 16.51
Low Navigational Freedom	n = 16 Mean =20.93 *SD* = 13.36	n = 16 Mean =24.45 *SD* = 12.95	n = 32 Mean = 22.69 *SD* = 13.06
Colum Totals	n = 32 Mean =19.99 *SD* = 13.39	n = 32 Mean =30.95 *SD* = 14.76	n = 64 Mean = 25.47 *SD* = 15.03

Graph 7: Knowledge Gain 2x2 ANOVA



8.4.1.1 No difference but suggestion of a trend, in *Knowledge Gain* by *Navigational Freedom*

H_0 2: μ Knowledge Gain $_{(HN)}$ = μ Knowledge Gain $_{(LN)}$

The first main effect of *Navigation* shows that *High Navigation Freedom* (M = 28.24, SD = 16.51) produced a very slightly higher *Knowledge Gain*, than *Low Navigation Freedom*

(M =22.69, SD = 13.06). A Two-way ANOVA produced only a modest trend to support this effect, $F(1,60) = 2.71$, $p = 0.105$; thus *Navigational Freedom* has no significant impact on *Knowledge Gained*.

8.4.1.2 Difference in *Knowledge Gain* by *Visual Fidelity*

H_a 1: μ Knowledge Gain $_{(HF)}$ > μ Knowledge Gain $_{(LF)}$

The second main effect of *Visual Fidelity* shows that *High Visual Fidelity* (M = 30.95, SD = 14.76) produced higher *Knowledge Gain*, than did *Low Visual Fidelity* (M =19.99, SD = 13.39). A Two-way ANOVA produced statistically strong and significant effects, $F(1,60) = 10.54$, $p = 0.0019$. Thus, *Visual Fidelity* has an impact on *Knowledge Gained*.

8.4.1.3 Interaction effects (*Visual Fidelity* x *Navigational Freedom*)

H_a 3: Interaction on Knowledge Gain: Visual Fidelity X Navigational Freedom

A Two-way ANOVA was run, which produced statistically significant evidence of interaction, $F(1, 60) = 4.85$, $p = 0.0315$. It appears that *High Visual Fidelity* and *High Navigation Freedom* have, combined, more of an impact, and at a higher magnitude on *Knowledge Gain* in virtual environments than do *Low Visual Fidelity* and *Low Navigation Freedom.*

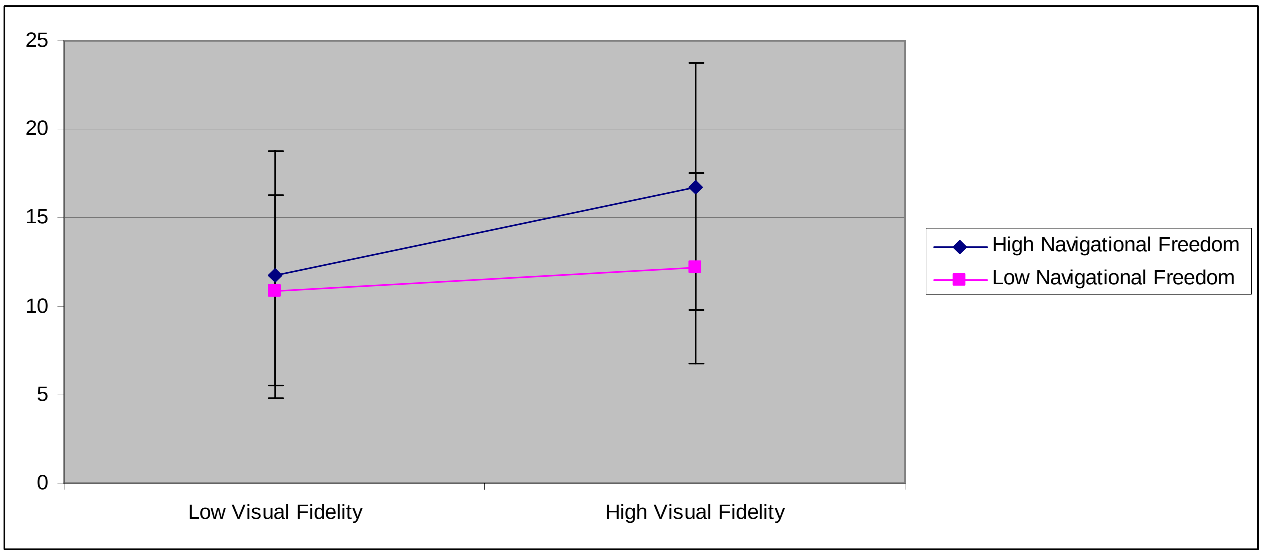
8.4.2 Salient Events

How did *Visual Fidelity* and *Navigational Freedom* impact *Salient Events* as measured by the count from the activity logs on the number of times a student would voluntarily stop exploring and stop to read fact cards or listen to a sprite? A Two-way ANOVA was used to test main effects and interaction effects for all variables under investigation.

Table 8: Main Study Contingency Table of Salient Events

	Low Visual Fidelity	High Visual Fidelity	Row Totals
High Navigational Freedom	n = 16 Mean =11.75 *SD* = 6.96	n = 16 Mean =16.75 *SD* =6.27	n = 32 Mean =14.25 *SD* = 6.99
Low Navigational Freedom	n = 16 Mean =10.87 *SD* =5.91	n = 16 Mean =12.18 *SD* = 4.9	n = 32 Mean =11.53 *SD* =5.38
Colum Totals	n = 32 Mean =11.31 *SD* = 6.37	n = 32 Mean =14.46 *SD* =6	n = 64 Mean = 12.89 *SD* = 6.34

Graph 8: Salient Events 2x2 ANOVA



8.4.2.1 No difference, but a strong trend, in *Salient Event* by *Navigation*

H_0 2: μ Salient Events $_{(HN)}$ = μ Salient Events $_{(LN)}$

The first main effect of *Navigational Freedom* show that *High Navigational Freedom* (M = 14.25, SD = 6.99) produced a slightly higher number of *Salient Events* than did *Low Navigational Freedom* (M =11.53, SD = 5.38). A Two-way ANOVA did not produced evidence that was statistically significant, only a strong trend that the *Salient Events* by *Navigational Freedom* are different, $F(1,60) = 3.23$, $p = 0.0773$. Thus, *Navigational Freedom* has no statistical impact on *Salient Events* but does show a strong trend.

8.4.2.2 Difference in *Salient Event* by *Visual Fidelity*

H_a 1: μ Salient Events$_{(HF)}$ > μ Salient Events$_{(LF)}$

The second main effect of *Visual Fidelity* show that *High Visual Fidelity* (M = 14.46, SD = 6) produced higher *Salient Events* than *Low Visual Fidelity* (M =11.31, SD = 6.37). A Two-way ANOVA produced evidence of statistically significant effects, $F(1,60) = 4.35$, $p = 0.00413$. Thus, *Visual Fidelity* has an impact on *Salient Event* activity.

8.4.2.3 No interaction effects (*Visual Fidelity* x *Navigational Freedom*)

H_0 3: No Interaction on Salient Events: Visual Fidelity X Navigational Freedom

A Two-way ANOVA was run, which produced no evidence of interaction, $F(1, 60) = 1.48$, $p = 0.2285$. It appears that varying *Visual Fidelity* and *High Navigational Freedom* has consistent effects on *Salient Event* activity, and can thus, be generalized.

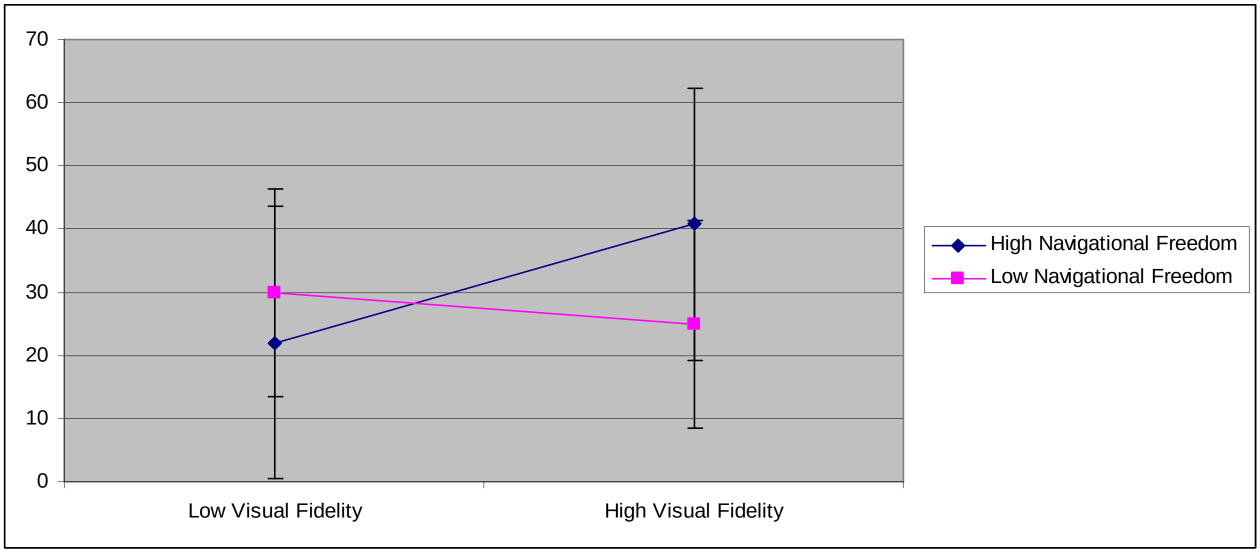
8.4.3 Fact Inquiry

How did *Visual Fidelity* and *Navigational Freedom* impact *Fact Inquiry*, as measured by the count of cards flipped by the student? A Two-way ANOVA was used to test main effects and interaction effects, for all variables under investigation.

Table 9: Main Study Contingency Table of Fact Inquiry

	Low Visual Fidelity	High Visual Fidelity	Row Totals
High Navigational Freedom	n = 16 Mean =22 *SD* = 14.01	n = 16 Mean =40.75 *SD* = 24.02	n = 32 Mean =31.375 *SD* = 21.56
Low Navigational Freedom	n = 16 Mean =29.93 *SD* = 18.94	n = 16 Mean =25 *SD* = 13.74	n = 32 Mean =27.468 *SD* = 16.47
Colum Totals	n = 32 Mean =25.96 *SD* = 16.88	n = 32 Mean=32.875 *SD* = 20.85	n = 64 Mean = 29.42 *SD* = 19.14

Graph 9: Fact Inquiry 2x2 ANOVA



8.4.3.1 No difference in *Fact Inquiry* by *Navigational Freedom*

H_a 2: μ Fact Inquiry $_{(HN)}$ =/= μ Fact Inquiry $_{(LN)}$

The first main effect of *Navigation* show that *High Navigational Freedom* (M = 31.375, SD = 21.56) produced slightly higher *Fact Inquiry* activity than did *Low Navigational Freedom* (M =27.468, SD = 16.47). A Two-way ANOVA produced no evidence to support this effect, $F(1,60) = 0.743$, $p = 0.3931$. Thus, *Navigational Freedom* has no statistical impact on *Fact Inquiry* activity.

8.4.3.2 No Difference in *Fact Inquiry* by *Visual Fidelity*

H_0 1: μ Fact Inquiry $_{(HF)}$ = μ Fact Inquiry $_{(LF)}$

The second main effect of *Visual Fidelity* show that *High Visual Fidelity* (M = 32.875, SD = 20.85) produced higher *Fact Inquiry* counts than did *Low Visual Fidelity* (M =25.96, SD = 16.88). A Two-way ANOVA produced no evidence of effect, $F(1,60) = 2.31$, $p = 0.1338$. Thus, *Visual Fidelity* has no impact on *Fact Inquiry* activity.

8.4.3.3 Significant interaction effects (*Visual Fidelity x Navigational Freedom)*

H_a 3: Interaction on Fact Inquiry: Visual Fidelity X Navigational Freedom

A Two-way ANOVA was run, which produced significant evidence of interaction, $F(1, 60) = 6.8$ $p = 0.0115$. It appears that varying *Visual Fidelity* and *Navigation Freedom* have inconsistent effects on *Fact Inquiry* activity.

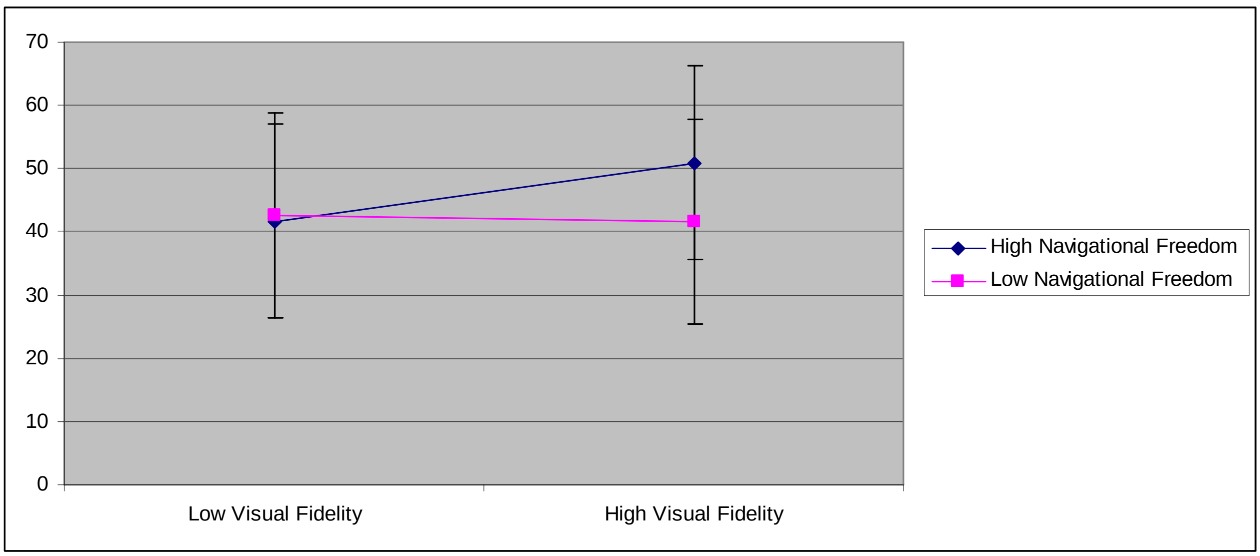
8.4.4 Time in System

How did *Visual Fidelity* and *Navigational Freedom* impact *Time in System*, where it measures the time a student volunteered to explore, inquire, and discover? A Two-way ANOVA was used to test main effects and interaction effects for all variables under investigation.

Table 10: Main Study Contingency Table of Time in System

	Low Visual Fidelity	High Visual Fidelity	Row Totals
High Navigational Freedom	n = 16 Mean= 41.875 *SD* = 17.78	n = 16 Mean =50.93 *SD* =11.29	n = 32 Mean =46.4 *SD* =15.36
Low Navigational Freedom	n = 16 Mean = 42.5 *SD* =17.8	n = 16 Mean = 41.56 *SD* =15.02	n = 32 Mean =42.03 *SD* =16.21
Colum Totals	n = 32 Mean =42.18 *SD* =3.09	n = 32 Mean=46.25 *SD* =13.91	n = 64 Mean =44.21 *SD* =15.82

Graph 10: Time in System 2x2 ANOVA



8.4.4.1 No difference in *Time in System* by *Navigational Freedom*

H_0 2: μ Time in System $_{(HN)}$ = μ Time in System $_{(LN)}$

The first main effect of *Navigation*, shows that *High Navigational Freedom* (M = 46.4, SD = 15.36) is close to identical to *Low Navigational Freedom* (M =42.03, SD = 16.21), for *Time in System*. A Two-way ANOVA supports this claim, F(1,60) = 1.24, p = 0.2699; thus *Navigational Freedom* has no statistical impact on *Time in System*.

8.4.4.2 No difference in *Time on Task* by *Visual Fidelity*

H_0 1: μ Time in System $_{(HF)}$ = μ Time in System $_{(LF)}$

The second main effect of *Visual Fidelity* shows that *High Visual Fidelity* (M =46.25, SD = 13.91) is close to identical to *Low Visual Fidelity* (M =42.18, SD = 3.09) for *Time in System*. A Two-way ANOVA supports this claim, $F(1,60) = 1.07$, $p = 0.3051$. Thus, *Visual Fidelity* has no impact on *Time in System*.

8.4.4.3 No interaction effects (*Visual Fidelity* x *Navigational Freedom*)

H_0 3: No Interaction on Time in System: Visual Fidelity X Navigational Freedom

A Two-way ANOVA was run, which produced no evidence of interaction, $F(1, 60) = 1.62$ $p = 0.208$. It appears that varying *Visual Fidelity* and *Navigational Freedom* have consistent effects on *Time in System*.

8.5. Main Study 2x2 ANOVA Results Discussion

The population from which the sample was taken was diverse. There were third, fourth, and fifth grade students from urban, suburban, and rural communities. However, when the sample was analyzed, it became apparent that there was sample bias. This was a volunteer sample, as is required by Federal Regulations that protect human subjects in research, and as such, all of the students reported high enjoyment of nature and above average skill with computers and high exposure to video games. All of the volunteers wanted to participate in a study on virtual reality and learning about nature. So, all of the findings must be interpreted in this light. Additionally and despite the geographical and demographical diversity, about 60% were girls, and 40% were boys. Most volunteers were white and from an upper social economic spectrum, and loved nature and were accomplished users of technology.

The point that all of the students liked nature implies that they were independently motivated by the subject material across all system conditions. The empirical part of the study was to find out the impact on learning, that certain environmental conditions, such as photorealistic or high-visual-fidelity representations of reality as opposed to cartoon-like or low-visual-fidelity representations of reality, can have. Not surprisingly, the *High Visual Fidelity* condition has more of an impact on *Knowledge Gained* (M=30.95, SD =14.76) when compared to the *Low Visual Fidelity* condition (M=19.99, SD = 13.39), but what is surprising is that there is a such a strong and highly significant impact for that learning condition, $F(1,60) = 10.54$, $p = 0.0019$. The other noteworthy result is the statistically significant interaction between *High Visual Fidelity* and *High Navigational Freedom*, as it has a larger impact, $F(1,60) = 4.85$, $p = 0.0315$, on *Knowledge Gained*, (M=37.44, SD = 13.88). This means that the independent variables are affecting the dependent variable in a non-consistent way. Why would combining *High Visual Fidelity* and *High Navigational Freedom* have a larger impact than either alone? One thought is that there are salient objects that the student wants to investigate, and in the high navigation condition, the child can go at will to that object. On the other hand, in the *Low Visual Fidelity* version, they may not see or perceive those objects as interesting, or if they do but they find themselves in the *Low Navigational Freedom* condition, they are prevented from approaching that object.

The next interesting finding concerns the salient objects that resulted in a change of behavior in the student. First, *Salient Events* are the count of times the student decided to stop navigating and to start inquiring and second, navigation and way-finding is under the child's free will. Thus, the choice is intrinsic as to which events they go to and about which they inquire. The data show that the *High Visual Fidelity* (M = 14.46, SD = 6) condition resulted in a significant and greater impact on *Salient Event* counts then did the *Low Visual Fidelity* (M =11.31, SD = 6.37) condition, $F(1,60) = 4.35$, $p = 0.00413$. That is to say that, in the photo-realistic version, the student decided to stop navigating, and either selected a fact card to read or stopped at a sprite to listen more often than in the other conditions. Why would children stop more often in the *High Visual Fidelity* version, especially since the cards and the sprites were identical to those in the *Low Visual Fidelity* version? This is open to future research, but it could be that the visually rich environment and context stimulates more curiosity than does the environment or context of a cartoon-like version. The data show that the *High Navigational Freedom* (M = 14.25, SD = 6.99) condition resulted in a strong trend and a possible impact on *Salient Event* counts, when compared to the *Low Navigational Freedom* (M =11.53, SD = 5.38) condition, F(1,60) = 3.23, p = 0.0773, and this evidence, combined with no evidence of interaction, F(1, 60) = 1.48, p = 0.2285, supports generalization.

The next interesting finding is that *Fact Inquiry* was not significantly impacted by either the *High Visual Fidelity* or the *Low Visual Fidelity*, or the *High Navigational Freedom* or *Low Navigational Freedom* conditions. Thus, these factors had no impact on the inquiry into facts. Much like a PowerPoint presentation, it is independent of the surroundings. This finding was expected, as the fact cards are part of the augmented user interface (UI) elements and were held constant across all system conditions. However, there was significant interaction, F(1, 60) = 6.8, p = 0.0115. One possibility is that the interaction can be explained by learning style that is correlated to gender, or that *Salient Events*, which were impacted by the system conditions, are correlated to *Fact Inquiry*, (r = 0.722, N = 64, p = 0.000). The ethnographic observations report that girls would look at and read all of the fact cards in the stack, reflecting a "Deep Inquiries" learning style, where the boys would only read the first few and then move on, reflecting a "Shallow Inquiries" learning style. It was observed that most boys and a few girls with high-percentage changes on test scores explored first in the *High-Navigation* conditions, flying to all edges of the world and as high as the system would allow for 20 to 40 minutes. Only after fully satisfying their curiosity did they come down to the ground and start to inquire in earnest. Also observed was that most girls and a few boys with high-percentage changes on test scores walked first and inquired in-depth for 20 to 40 minutes; only after their curiosity was satisfied did they fly. Flying and exploring the space allowed for holistic understanding of the space. And walking with diligent drilling down the fact inquiry allowed for specific detailed factual knowledge acquisition, and only the children who did both seemed to understand all of the material. The interesting observation is that, given an open-ended study, the child selected what kind of learning activity to do and when to do it, thus self-regulating and maximizing learning opportunities on their own. This is even more interesting as the *Time in System* was statistically the same across all conditions.

The last finding is very surprising, in that the total time spent in each condition, *Time in System* for both factors, showed no significant main effects *Navigational Freedom*, $F(1,60) = 1.24$, $p = 0.2699$; and *Visual Fidelity*, $F(1,60) = 1.07$, $p = 0.3051$ and no interaction, $F(1, 60) = 1.62$ $p = 0.208$. However, the design did not allow the students to go over 60 minutes, and 40% of all students were forced to stop across all conditions. This is not to say that the conditions were the same; in fact, future work may not have a time limit at all and so may be able to more accurately measure the enjoyment of the condition by the *Time in System*.

The most important results are the evidence of the *Teachable Moment* concept, as it was observed in the real-world study with the *Salamander Effect*, as well as the strong empirical evidence presented in the main study for *Salient Events* under the *High Visual Fidelity* condition and as a strong trend under the *High Navigational Freedom* condition.

8.6. Data Exploration of Gender and Learning Styles

As was observed in the main study, in-situ activities were associated with learning styles that appeared to cluster around gender, ***even though this study was not designed for gender comparison,*** this section will analyze the data in this light. Boys, in all conditions, tended to explore their environment first, and if they could fly, they would seek the top of the world and all four corners. If they were in the *Low Navigational Freedom* condition, the boys became observably frustrated and even angered with the path constraint, as it restricted their movement. This behavior lasted for the first 20 to 40 minutes before they went on to engage in the *Fact Inquiry* or *Salient Event* investigation. This style, of “Broad Explorer” first and “Deep Inquirer” second, was typical across conditions by boy gender. Girls, on the other hand, tended to systematically inquire at the ground level, being “Deep Inquirers” first and staying on the path without frustration, independent of flying mode availability, also for the first 20 to 40 minutes, before engaging in the “Broad Explorer” behavior. The “Broad Explorer” style is typical for spatial exploration and survey knowledge acquisition, while the “Deep Inquirer” is typical for detailed factual knowledge acquisition. The two styles correlated by gender were opposite in activity over time — or orthogonal to each other. It was interesting to observe that the total voluntary time of forty minutes to one hour was sufficient to convert to the opposite style.

Observed was a third style, "Dive Bomber," used by both girls and boys with very high-percentage changes in test scores, who would strategically switch between the styles, based on immediate need, context, task, and environmental salience.

8.6.1 No Difference by Gender across all SEEE System Conditions (N=64)

Even though this study was not designed for gender comparison, at a high level of statistical analysis, it appears that there is no difference in gender-correlated learning styles**.** The following is ***only an exploration*** of the data to probe for future hypothesis on which to base future work as ***cell sample size and variances are not equal when transformed on these dimensions***. Transforming the data into the *Gender* (Girls, Boys) and *System Conditions* (HFHN, LFHN, HFLN, LFLN), and using a 2x4 ANOVA for Independent Samples, with *Gender* x *System Condition* as the factors, the main effect of *Gender* is not significant, $F(1,56) = 0.25$, $p = 0.619$. Both groups experienced the same percent change in test scores: *Boys* (N=25, M = 24.93, SD = 13.23) and *Girls* (N= 39, M = 26.56, SD = 15.96). Not surprisingly, *System Condition* is a significant main effect, with $F(3,56) = 6.14, p = 0.0011$): however there is interaction, with $F(3, 56) = 3.82$, $p = 0.0146$.

8.6.2 Gender in the Orthogonal System Conditions (N=32)

Given the strong ethnographic data on different learning styles clustered around gender and the evidence of the statistical interaction in the main factors, the cells that represent orthogonal *System Conditions* warrant special attention. If the *System Condition* of *High Visual Fidelity High Navigational Freedom* is compared to that of *Low Visual Fidelity* and *Low Navigational Freedom* by *Gender*, we see a new future hypothesis: *Gender* clustered learning styles may benefit from different *System Conditions* for learning. A future study will have to design the research explicitly to answer this question.

There is interesting data and statistics that warrant future investigation. The percentage change in test scores by *Gender* is impacted by the orthogonal *System Conditions*. Transforming the data into the *Gender* (Girls, Boys) and *System Condition* (HFHN, LFLN), and using a 2x2 ANOVA for Independent Samples, with *Gender* x *System Condition* as the factors, the main effect of *Gender* is significant, $F(1,28) = 4.61$, $p = 0.041$. Each group experienced slightly different percentage changes in test scores: *Boys* (n=14, M = 24.17, SD = 13. 3) and *Girls* (n= 18, M = 33.59, SD = 16.66). Not surprisingly, *System Condition* also shows a significant main effect, with $F(1,28) = 13.42$, $p = 0.001$). The entire 2X2 ANOVA produced evidence of interaction, with $F(1, 28) = 4.83$, $p = 0.036$. Future research will investigate typical girl-clustered and boy-clustered learning styles.

Predicted is that *Girls* will be positively affected by a photorealistic virtual environment with full freedom of navigation, and negatively affected by a cartoon-like virtual environment that restricts navigation.

H_0 1: μ Girls Knowledge Gain $_{(HFHN)}$ = μ Girls Knowledge Gain $_{(LFLN)}$

H_a 1: μ Girls Knowledge Gain $_{(HFHN)}$ > μ Girls Knowledge Gain $_{(LFLN)}$

Also predicted, is that *Boys* will not be impacted by a photorealistic virtual environment, and may actually benefit from restricted navigational movement. Future work will need to investigate how IQ, gender, learning styles, and factors in the environment interact especially on typical boy- and girl- clustered learning styles, and on gender-neutral learning styles.

H_0 2: μ Boys Knowledge Gain $_{(HN)}$ = μ Boys Knowledge Gain $_{(LN)}$

H_a 2: μ Boys Knowledge Gain $_{(HN)}$ < μ Boys Knowledge Gain $_{(LN)}$

H_0 3: μ Boys Knowledge Gain $_{(HF)}$ = μ Boys Knowledge Gain $_{(LF)}$

H_a 3: μ Boys Knowledge Gain $_{(HF)}$ =/= μ Boys Knowledge Gain $_{(LF)}$

8.7. Main Study Emotion and Subjective Attitudinal Survey Results

8.7.1 Main Study Interview Results

Students reported favorable feedback and impressions overall and in all conditions. Most students thought the experience was too fun to be used in schools, and most requested a copy of the software to use at home for play. Additionally, children's feedback reflected an interest in which wild plants in their own backyards were edible, poisonous, and useful for medicine. Many wanted to go to the real Trillium Trail. The following is an interview excerpt from student number 38, a Gifted (IQ>130) girl, in the HFLN condition:

Post-Experience Attitude Interview:

Please answer the following questions:

1. What did you enjoy the most in the Virtual Field Trip?

I enjoyed wandering around and seeing what species, where they grew, high or low, near the stream, seeing the plants and finding out the interesting facts was fun…

2. What did you dislike the most about the Virtual Field Trip?

That I had to stay on the path, and I got lost, because I was disoriented and could not see where I was..

3. How would you improve the Virtual Field Trip?

I think I would have some sort of way to get a birds-eye-view to see where you were and to have the paths marked more clearly so you could see where you were…

4. What was it that you learned?

I learned that plants prefer valleys to plateau because there is more water and nutrient rich soil at the bottom of valleys.

5. Describe your ideal Virtual Field Trip?

I would like a virtual filed trip to the Great Barrier Reef.

6. Describe how you felt in the Virtual Field Trip.

It was very interesting and very fun to go around and learning about plants, and having a realistic experience, but knowing that it was virtual, knowing that it was just as factual as a real life nature hike, but it was different too, because of having to stay on the trail and the sprites…

8.7.2 Main Study Survey Results: Emotion, Affect, Aesthetic, and Subjective Attitudes

The data reported in the survey represents the emotional, affective, aesthetic, and subjective attitudinal responses to only one experienced system condition experience, not all four. The findings must be viewed in this light. It is impossible to compare and contrast one experience in only one condition across multiple conditions without a counterbalanced design for contrast and comparison. Therefore, the data presented here (Table 11.), where the students experienced only one condition, is quite different from the data presented in the pilot study, where the students experienced two conditions in opposite order. Also, a parametric test, One-way ANOVA is used instead of a non-parametric test, due to the larger sample size.

Table 11: One-way ANOVA Main Study Survey Results

One-way ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Exploration	Between Groups	5.468	3	1.823	2.004	.123
	Within Groups	52.742	58	.909		
	Total	58.210	61			
Inquiry	Between Groups	1.670	3	.557	.413	.744
	Within Groups	78.217	58	1.349		
	Total	79.887	61			
Learning	Between Groups	.299	3	.100	.081	.970
	Within Groups	71.121	58	1.226		
	Total	71.419	61			
Curiosity	Between Groups	8.201	3	2.734	2.051	.117
	Within Groups	77.283	58	1.332		
	Total	85.484	61			
Calm	Between Groups	11.660	3	3.887	2.511	.067
	Within Groups	89.775	58	1.548		
	Total	101.435	61			
Excitement	Between Groups	8.397	3	2.799	1.934	.134
	Within Groups	83.942	58	1.447		
	Total	92.339	61			
Awe and Wonder	Between Groups	17.323	3	5.774	4.795	.005
	Within Groups	69.854	58	1.204		
	Total	87.177	61			
Frustration	Between Groups	1.088	3	.363	.354	.787
	Within Groups	59.508	58	1.026		

	Total	60.597	61			
Disinterest	Between Groups	1.272	3	.424	.491	.690
	Within Groups	50.083	58	.864		
	Total	51.355	61			
Desire to Create	Between Groups	6.915	3	2.305	1.896	.140
	Within Groups	70.504	58	1.216		
	Total	77.419	61			
Desire to Share	Between Groups	9.601	3	3.200	2.049	.117
	Within Groups	90.608	58	1.562		
	Total	100.210	61			
Reexperience	Between Groups	4.963	3	1.654	1.499	.224
	Within Groups	64.021	58	1.104		
	Total	68.984	61			
Presence	Between Groups	7.381	3	2.460	1.321	.276
	Within Groups	108.054	58	1.863		
	Total	115.435	61			
Beauty	Between Groups	1.901	3	.634	.532	.662
	Within Groups	69.083	58	1.191		
	Total	70.984	61			

While this violates the logic of the design, a direct comparison was conducted to explore the data from the main study, showing no statistical difference between students' emotional, affective, aesthetic, and subjective attitudes on their experiences in different system conditions The number of hypotheses is high (14), and thus, at the $p < 0.001$ level, there is no statistical difference among the conditions. In the future, a counterbalanced design will allow for multiple system condition experiences to be balanced by order, and thus a more meaningful subjective attitudinal comparison. However, as is common practice, a p value of 0.05 could be viewed as acceptable, and thus there are interesting findings to report. The only emotional reactions that are close to significant, using a One-way ANOVA, (Table 12.) are *Calm*, ($F(3,58) = 2.511$, $p = 0.067$, and *Awe and Wonder*, $F(3,58) = 4.975$, $p = 0.005$.

Table 12: Difference in Subjective Survey Descriptives (N=64)

Difference ($p < 0.05$)	Median (Mean, SD)		Median (Mean, SD)		F(3,58)
	HFHN	LFHN	HFLN	LFLN	p-value
Awe and Wonder	"Mostly" 4.00 (3.87, 0.61)	"Average" 3.00 (3.07, 1.28)	"Somewhat" 2.00 (2.53, 1.12)	"Mostly" 4.00 (3.68, 1.25)	0.005
Calm	"Mostly" 4.00 (3.81, 0.98)	"Average" 3.00 (3.00, 1.6)	"Average" 3.00 (3.20,1.32)	"Mostly" 4.00 (4.06, 0.99)	0.067

Table 13: No Difference in Subjective Survey Descriptives (N=64)

No difference (*p* > 0.05)	Median (Mean, SD)		Median (Mean, SD)		F(3,58)
	HFHN	LFHN	HFLN	LFLN	p-value
Exploration	"A Great Deal" 5.00 (4.56, 0.63)	"Mostly" 4.00 (4.07, 1.10)	"Mostly" 4.00 (3.73, 1.09)	"Mostly" 4.00 (4.06, 0.92)	0.123
Inquiry	"Mostly" 4.00 (3.75, 1.06)	"Mostly" 4.00 (3.46, 1.3)	"Average" 3.00 (3.53,1.18)	"Mostly" 4.00 (3.87, 1.08)	0.744
Learning	"Mostly - A Great Deal" 4.50 (4.18, 1.05)	"A Great Deal" 5.00 (4.07, 1.22)	"Mostly" 4.00 (4.00, 1.22)	"Mostly" 4.00 (4.00, 1.06)	0.970
Curiosity	"A Great Deal" 5.00 (4.56, 0.63)	"Mostly" 4.00 (4.07, 1.10)	"Mostly" 4.00 (4.07, 1.10)	"Mostly" 4.00 (4.07, 1.10)	0.117
Excitement	"Mostly" 4.00 (4.31, 0.70)	"Average" 3.00 (3.33, 1.29)	"Average" 3.00 (3.53, 1.12)	"Average" 3.00 (368, 1.53)	0.134
Frustration	"Somewhat" 2.00 (1.81, 0.65)	"Somewhat" 2.00 (1.80, 1.08)	"Somewhat" 2.00 (2.133, 1.24)	"Somewhat" 2.00 (1.93, 0.99)	0.787
Disinterest	"Not at All" 1.0 (1.25, 0.44)	"Not at All" 1.00 (1.53, 1.12)	"Not at All" 1.00 (1.4, 0.63)	"Not at All" 1.00 (1.62, 1.25)	0.690
Desire to Create	"A Great Deal" 5.00 (4.50, 0.82)	"Mostly" 4.00 (3.67, 1.40)	"Mostly" 4.00 (3.87, 1.19)	"A Great Deal" 5.00 (4.31, 0.95)	0.140
Desire to Share	"A Great Deal" 5.00 (4.43, 0.72)	"A Great Deal" 5.00 (3.80, 1.56)	"Mostly" 4.00 (3.33, 1.34)	"Mostly" 4.00 (3.9, 1.24)	0.117
Reexperience	"A Great Deal" 5.00 (4.37, 0.88)	"Mostly" 4.00 (3.60, 1.24)	"Mostly" 4.00 (3.87, 1.06)	"Mostly" 4.00 (4.06, 0.99)	0.224
Presence	"Mostly" 4.00 (3.81, 1.27)	"Average" 3.00 (2.93, 1.33)	"Mostly" 4.00 (3.73, 1.16)	"Mostly - A Great Deal" 4.50 (3.62, 1.63)	0.276
Beauty	"Mostly" 4.00 (4.00, 0.96)	"Mostly" 4.00 (3.73, 1.16)	"A Great Deal" 5.00 (4.20, 1.10)	"A Great Deal" 5.00 (4.12, 1.20)	0.662

The fact that there is no standard measurement for terms and responses like *Beauty*, *Awe and Wonder*, *Excitement*, *Learning*, *Inquiry*, and the others, makes this a very challenging problem to frame. We claim that the external definition is not important; it is the internal, subjective, and emotional definition that matters. So, if the rank is a 5 = "A Great Deal," we conclude that, in the student's opinion, she learned a great deal. *This survey is a subjective, attitudinal, and* *personal survey on the one experience in isolation only.* Therefore, all subjective rankings were identical across all system conditions, given that the student only experienced one condition. The only ones that did show differences were in the ranking assessment of *Awe and Wonder* and *Calm*.

When exploring emotions and attitudes across all of the SEEE system dimensions, the Spearman Rank Correlation Coefficient is reported, (Table 14), and the main findings show a significant and strong correlation between students' subjective rankings of *Inquiry* and *Learning* (r = 0.70, N = 64, p = 0.00). Table 14. shows many interesting correlations to investigate for future studies, especially on the role of emotions in learning and perception in such systems, particularly the effect of *Awe and Wonder*, *Excitement*, *Presence*, *Beauty,* and the *Desire to Create*.

However, the true value of this survey is as a correlation table across all four system conditions relative to the other empirical variables in the main study empirical design. If the rankings are correlated to empirical data and can be used in future regression equations, then we can start to understand and use subjective rankings as more effective user interface (UI) design tools in future software design and in the development of virtual environments for education.

Table 14: Main Study Survey Results Spearman Rank Correlation Table, (N=64)

Spearman Correlation (N= 62)

	Exploration	Inquiry	Learning	Curiosity	Calm	Excitement	Awe and Wonder	Frustration	Disinterest	Desire to Create	Desire to Share	Desire to Re-experience	Presence	Beauty
Exploration	1.000	.239	.366**	.308*	.130	.473**	.285*	-.078	-.402**	.327**	.378**	.384**	.262*	.096
p (2-tail)	.	*.061*	*.003*	*.015*	*.315*	*.000*	*.025*	*.548*	*.001*	*.010*	*.002*	*.002*	*.040*	*.456*
Inquiry	.239	1.000	.700**	.347**	.265*	.513**	.364**	-.351**	-.446**	.459**	.436**	.239	.397**	.420**
p (2-tail)	.061	.	.000	.006	.037	.000	.004	.005	.000	.000	.000	.061	.001	.001
Learning	.366**	.700**	1.000	.354**	.139	.550**	.506**	-.303*	-.480**	.336**	.464**	.168	.541**	.376**
p (2-tail)	*.003*	*.000*	.	*.005*	*.280*	*.000*	*.000*	*.017*	*.000*	*.008*	*.000*	*.192*	*.000*	*.003*
Curiosity	.308*	.347**	.354**	1.000	-.026	.548**	.332**	-.005	-.428**	.413**	.347**	.248	.401**	.305*
p (2-tail)	*.015*	*.006*	*.005*	.	*.841*	*.000*	*.008*	*.967*	*.001*	*.001*	*.006*	*.052*	*.001*	*.016*
Calm	.130	.265*	.139	-.026	1.000	.214	.402**	-.304*	-.323*	.334**	.348**	.210	.419**	.450**
p (2-tail)	*.315*	*.037*	*.280*	*.841*	.	*.094*	*.001*	*.016*	*.010*	*.008*	*.006*	*.101*	*.001*	*.000*

Excitement	.473**	.513**	.550**	.548**	.214	1.000	.415**	-.427**	-.600**	.585**	.556**	.484**	.528**	.377**
p (2-tail)	*.000*	*.000*	*.000*	*.000*	*.094*	*.*	*.001*	*.001*	*.000*	*.000*	*.000*	*.000*	*.000*	*.003*
Awe and Wonder	.285*	.364**	.506**	.332**	.402**	.415**	1.000	-.147	-.434**	.432**	.502**	.274*	.577**	.506**
p (2-tail)	*.025*	*.004*	*.000*	*.008*	*.001*	*.001*	*.*	*.254*	*.000*	*.000*	*.000*	*.031*	*.000*	*.000*
Frustration	-.078	-.351**	-.303*	-.005	-.304(*)	-.427**	-.147	1.000	.442**	-.296*	-.304*	-.257*	-.302*	-.261*
p (2-tail)	*.548*	*.005*	*.017*	*.967*	*.016*	*.001*	*.254*	*.*	*.000*	*.020*	*.016*	*.044*	*.017*	*.041*
Disinterest	-.402**	-.446**	-.480**	-.428**	-.323*	-.600**	-.434**	.442**	1.000	-.433**	-.462**	-.489**	-.577**	-.227
p (2-tail)	*.001*	*.000*	*.000*	*.001*	*.010*	*.000*	*.000*	*.000*	*.*	*.000*	*.000*	*.000*	*.000*	*.076*
Desire to Create	.327**	.459**	.336**	.413**	.334**	.585**	.432**	-.296*	-.433**	1.000	.431**	.517**	.482**	.456**
p (2-tail)	*.010*	*.000*	*.008*	*.001*	*.008*	*.000*	*.000*	*.020*	*.000*	*.*	*.000*	*.000*	*.000*	*.000*
Desire to Share	.378**	.436**	.464**	.347**	.348**	.556**	.502**	-.304*	-.462**	.431**	1.000	.321*	.394**	.434**
p (2-tail)	*.002*	*.000*	*.000*	*.006*	*.006*	*.000*	*.000*	*.016*	*.000*	*.000*	*.*	*.011*	*.002*	*.000*
Desire to Re-experience	.384**	.239	.168	.248	.210	.484**	.274*	-.257*	-.489**	.517**	.321*	1.000	.397**	.240
p (2-tail)	*.002*	*.061*	*.192*	*.052*	*.101*	*.000*	*.031*	*.044*	*.000*	*.000*	*.011*	*.*	*.001*	*.060*
Presence	.262*	.397**	.541**	.401**	.419**	.528**	.577**	-.302*	-.577**	.482**	.394**	.397**	1.000	.589**
p (2-tail)	*.040*	*.001*	*.000*	*.001*	*.001*	*.000*	*.000*	*.017*	*.000*	*.000*	*.002*	*.001*	*.*	*.000*
Beauty	.096	.420**	.376**	.305*	.450**	.377**	.506**	-.261*	-.227	.456**	.434**	.240	.589**	1.000
p (2-tail)	*.456*	*.001*	*.003*	*.016*	*.000*	*.003*	*.000*	*.041*	*.076*	*.000*	*.000*	*.060*	*.000*	*.*

** *Correlation is significant at the 0.01 level (2-tailed).* * *Correlation is significant at the 0.05 level (2-tailed).*

8.8. Main Study Correlations

Pearson Correlations were run (Table 15.) to generate statistics on the empirical data of the main study. The correlation results confirm the main study 2x2 ANOVA results. The positive and significant correlations for the *Visual Fidelity* factor with *Knowledge Gained* (r = 0.367, N = 64, p = 0.003) and with *Salient Events* (r = 0.251, N = 64, p = 0.046). Not surprisingly, the correlations for the *Navigational Freedom* factor are insignificant, which is consistent and supports the finding of the main study.

Also consistent with the main study results, is the evidence of the orthogonal relationship between the *Fact Inquiry* and the *Visual Fidelity* and *Navigational Freedom* factors of the main study 2X2 ANOVA, with no correlation to either factor in the table. However, relating the *Fact Inquiry* back to the higher-level learning goal, we see that there is a positive and significant correlation between *Fact Inquiry* and *Knowledge Gained* (r = 0.374, N = 64, p = 0.002). These correlations will be explored in future work of the Main Study SEEE Tripartite Regression and Markov Models.

Table 15: Pearson Correlations (N=64) Sig(2-tail)

	Knowledge Gained (Percent Change Test Scores)	**VE *Visual Fidelity*** Fidelity Salience Score	**VE *Navigational Freedom*** Navigation Salience Score	**UI *Salient Events*** Teachable Moments	**UI *Fact Inquiry*** Fact Cards Inquired	***Time*** Time in System
Knowledge Gained (Percent Change Test Scores)	1	.367(**)	.186	.455(**)	.374(**)	.245
		.003	.141	.000	.002	.051
VE: *Visual Fidelity* Fidelity Salience Score	.367(**)	1	.000	.251(*)	.182	.129
	.003		1.000	.046	.150	.308
VE: *Navigational Freedom* Navigation Salience Score	.186	.000	1	.216	.103	.139
	.141	1.000		.086	.419	.272
UI: *Salient Events* Teachable Moments	.455(**)	.251(*)	.216	1	.722(**)	.644(**)
	.000	.046	.086		.000	.000
UI: *Fact Inquiry* Fact Cards Inquired	.374(**)	.182	.103	.722(**)	1	.610(**)
	.002	.150	.419	.000		.000
Time: Time in System	.245	.129	.139	.644(**)	.610(**)	1
	.051	.308	.272	.000	.000	

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Spearman Correlations were run (Table 16.) to generate statistics on the emotional, affective, aesthetic, and subjective attitudinal data that was intended to capture emotion and affective reactions to the experience. The only emotional variable that shows a positive correlation with *Knowledge Gained* is that of *Awe and Wonder* (r = 0.273, N = 64, p = 0.032). Noteworthy are the high correlations with *Beauty* and *Awe and Wander* (r =0.506, N = 64, p =0.000), and the overall *Total Attitudinal Survey* ranking (r = 0.727, N = 64, p = 0.000). This shows the correlation and relationships between *Beauty*, whatever it may be for the individual, the emotional reaction of *Awe and Wonder*, and the empirical data on test scores, *Knowledge Gained*. ***This is a major contribution as it links beauty to empirical learning results.***

Table 16: Spearman's rho Correlations (N=64) Sig(2-tail)

	Knowledge Gained (Percent Change Test Scores)	Awe and Wonder	Beauty	Total Attitudinal Survey
Knowledge Gained (Percent Change Test Scores)	1.000	.273(*)	.148	.210
	.	.032	.252	.096
Awe and Wonder	.273(*)	1.000	.506(**)	.727(**)
	.032	.	.000	.000
Beauty	.148	.506(**)	1.000	.683(**)
	.252	.000	.	.000
Total Attitudinal Survey	.210	.727(**)	.683(**)	1.000
	.096	.000	.000	.

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

While correlation is not causality, these correlations represent interesting relationships to investigate in future research. The patterns of correlation presented here give the systems designer a place to start.

9. Conclusion

This is a review of the major findings in both the pilot study and the main study. The results are discussed and placed in theoretical context. The results are presented in a format that can guide design trade-off decisions for the HCI researcher, designer, and practitioner. Last, an interpretation of the findings is offered for educators, teachers and anyone interested in using virtual environments for education in practice.

9.1. Significant Findings

Over the past decade, virtual reality has been investigated for use in education (Youngblut, 1998). The early research framed the educational benefits within the context of constructivist pedagogy (Dede, 1995; Wickens, 1992; Winn, 1993), within the educational pedagogy of scientific inquiry (Jackson & Fagan, 2000; Johnson, et al., 1999), or within the context of the advantages of social collaboration (Barab et al., 2007; Dede et al., 2005; Roussou, Johnson, et al., 1997). Some modeled real-world environments, such as museums, to research the effects on individual inquiry (Corbit, 2000). None of the prior work considered a child-computer-interaction framing, independent of pedagogy and focused on the impact of user interface parameters such as image quality and navigational freedom. A major contribution of this research was in the construction of the Virtual Trillium Trail, as it represents one square mile of biologically accurate scientific plot study data. Because it is a virtual environment based on statistical data visualization and not fantasy, it allowed for a highly realistic and scientifically true-to-life visualization, and for a planned orthogonal contrast with exceptionally high internal validity in both system and statistical design. Future software research and development will be in automatic virtual ecology generation. What is called “Desktop Virtual Reality” is within a price point that will make it a viable distribution platform for educational and learning applications. The practical appeal of low-cost, high-impact Desktop Virtual Reality applications for educational field trips is especially important as a way to provide access to inaccessible locations, such as the Amazon Rain Forest, the African Savanna, the Canadian-Russian Boreal Forests, the Great Barrier Reef, and many other locations of natural wonder and ecological richness. In addition to these more “exotic” locations, there are many natural wonders found in our own backyards. Empowering children to learn at their own pace, style, and in their own time is critical.

The second major contribution of this research is that it focused on the child-computer interactions, activities, and perceptual-emotional reactions to the software with an eye to supporting the child's goals of intrinsic learning. It builds upon prior research on learning, transfer, and procedural knowledge in virtual environments used in training. Most recent and relevant research using virtual reality is in medical training; in this area, VR has been shown to shorten learning curves (Aggarwal, Ward, Balasundaram, Sains, Athanasiou, & Darzi, 2007), and real-world skills have been shown to transfer (Cromby, Standen, Newman, & Tasker, 1996). This research extends the understanding of this field into the factors that influence learning in such virtual environments, especially learning activity of young children. Largely neutral from educational pedagogy, this research showed that the system can affect learning activity. Of critical importance is evidence in the pilot study that virtual-reality field trips for students may be used to ***prime*** before and to ***reinforce*** after a real field trip. This research also showed ***transfer effects*** on in-situ learning activity, and in both directions. Thus, to maximize impact, virtual environments may augment educational practices and not replace them. The other large contribution was in the activity analysis of the real field trip, with the *Salamander Effect* as strong evidence that *Salient Events* are critical design features of such systems. A main part of this thesis is the importance of such events, in terms of creating a *Teachable Moment* and leveraging episodic memory, and how these events may be intentionally designed into a user interface, such as was done for the main study with *Salient Events.*

The main empirical contribution was produced by the 2x2 ANOVA with the factors of *Visual Fidelity* and *Navigational Freedom,* and the evidence of these factors' different effects on *Knowledge Gained*. The tool has an impact on learning. Learning can occur in terms of knowledge gained as measured by a pre-test and a post-test of facts and concepts. The MaxwellWorld project of Project Science Space showed gains of close to 20% (Dede et al., 1999; Salzman et al., 1996), and the Virtual Environments in Biology Teaching project showed gains of close to 50% (Mikropoulos et al., 2003). The social and collaborative Multi-User Virtual Environment (MUVE), showed gains of close to 35% (Dede et al., 2005), and yet other research raised important questions about engagement and guided inquiry, making a strong case for structure and scaffolding, especially with respect to procedural-knowledge acquisition for mathematics (Roussou, Oliver, & Slater, 2006). None of prior work considered the design of the system and the impacts that the design parameters, such as image quality or style of navigation, could have on learning, as well as on emotional or subjective reactions to the experience. This research extends those findings and knowledge on the design factors in the system.

The main study showed that the *High Visual Fidelity* condition has more of an impact on *Knowledge Gained* (M = 30.95, SD = 14.76) when compared to the *Low Visual Fidelity* condition (M = 19.99, SD = 13.39), with F(1,60) = 10.54, p = 0.0019. There is interaction between *Fidelity* and *Navigational Freedom,* F(1,60) = 4.85, p = 0.0315, with the largest impact (M = 37.44, SD = 13.88) on *Knowledge Gained*. One explanation for the interaction is that there are salient objects that the student wants to investigate, and in the *High Navigational Freedom* condition, the student is allowed to go to those objects. Whereas, in the *Low Visual Fidelity* condition, the student may not see or perceive those objects as interesting, or if the student does, but if in the *Low Navigational Freedom* condition they are prevented from approaching that object. Therefore, this evidence strongly supports the claim that photorealistic-quality virtual environments are superior to cartoon-quality versions for education and learning systems. There is also a case for preferring the combination of photorealistic and free navigation in such systems.

The next major contribution connects the significance of the *Teachable Moment* (Bentley, 1995), to user interface design and the use of such *Salient Events* to enhance the user interface and learning. The main study system implemented *Salient Events* and thereby supported the child's innate desire to know. The data show that the *High Visual Fidelity* condition (M = 14.46, SD = 6), resulted in higher and significant impacts on *Salient Event* counts than the *Low Visual Fidelity* condition (M =11.31, SD = 6.37), F (1,60) = 4.35, p = 0.00413. Thus, in the photorealistic version, the student decided to stop navigating, and either selected a fact card to read or stopped at a sprite to listen more often than in the other conditions. Why would children stop and inquire more often in the *High Visual Fidelity* version, especially since the cards and the sprites were identical in both the *High Visual Fidelity* and the *Low Visual Fidelity* versions?

This is open to future research, but it could be that the visually rich environment and the context stimulated a need to know, more often than did the environment or context of a cartoon-like world. The data show that the *High Navigational Freedom* condition (M = 14.25, SD = 6.99) resulted in a strong statistical trend on *Salient Event* counts, when compared to the *Low Navigational Freedom* condition (M =11.53, SD = 5.38), F (1,60) = 3.23, p = 0.0773, and this evidence, combined with no evidence of interaction, F(1, 60) = 1.48, p = 0.2285, trends toward generalization. This is perhaps the most important evidence in the research, as it was relevant in the pilot study and observed in the ethnographic activity analysis of learning on the real field trips. *High Visual Fidelity* and *High Navigational Freedom* both increase *Salient Event* finds, which are critical design features for educational virtual environments, especially since *Salient Events* are moderately, positively correlated with *Knowledge Gained* (r = 0.455, N = 64, p =0.000).

Emotional and subjective attitudes were investigated in the post-experience assessment of the system and learning experience. The main study only allows a correlation of ranked items, as a direct comparison between system conditions would be meaningless. However, there are important patterns of importance and significance to note. *Total Attitude* is strongly, positively and, significantly correlated with *Awe and Wonder* (r = 0.727, N = 64, p = 0.000). Also important is the moderately strong, positive, and significant correlation of *Beauty* with *Awe and Wonder* (r = 0.506, N = 64, p = 0.000). *Awe and Wonder* was the only subjective emotion significantly correlated, moderately-weakly, to *Knowledge Gained* (r = 0.273, N = 64, p =0.000). These findings are critical to the main research question on intrinsically motivated exploration and inquiry for self-directed learning activity. The results provide evidence that support ideas expressed before on the affective and emotional requirements for self-directed learning and motivation, such as that the activity is part "play" (Papert, 1993; Resnick, 2004) and part "flow" (Csikszentmihalyi, 1991). We have evidence that an emotional sense of "*Awe and Wonder*" is correlated with knowledge gain and, as such, is an important design factor for such systems. Additionally, this evidence supports the claim that some of the real wonder and beauty was communicated in the software for the learning experience.

Future research will investigate the complexity and causality of such interactions between the child's mental model, the virtual environment, and the user interface in the form of regression equations, partial differential equations, and Markov models.

9.2. Message for HCI Designers

High fidelity, when combined with high navigation in virtual environments, has a higher impact on intrinsic learning activity for the same amount of time. So, if you want to get the most out of the learning activity in virtual-reality field trips, and can make it photorealistic with free navigation, which is a design choice, an HCI parameter, then do so, because there is scientific evidence that it has a positive impact. Also, there is interaction with the *High Visual Fidelity* condition in combination with the *High Navigational Freedom* condition, so the combined impact is higher than it is with each condition separately in place, which is also a design decision. Use *High Visual Fidelity* and *High Navigational Freedom* together for the greatest impact (38% knowledge gain) in virtual environments for intrinsic learning. The powerful combination is to combine the photorealistic and free navigation features together in a design for improved learning.

The other interpretation is that the *Low Visual Fidelity High Navigational Freedom* and the *Low Visual Fidelity Low Navigational Freedom* system conditions have similar knowledge gains, of about 20% — so you are free to make that design choice. In other words, *Low Visual Fidelity Low Navigational Freedom* system conditions will have about the same impact on learning as a *Low Visual Fidelity High Navigational Freedom* system condition, so choose the more cost-effective system as they will have the same learning impact. This finding may be extensible to indicate that Flash based systems are just as effective as cartoon quality virtual reality systems, *ceteris paribus*.

The *Salient Events* reflect the student's choice to stop exploring and to start inquiring. Since *Salient Events* represent the child's innate decision to gain knowledge, it is a direct link to the *Salamander Effect* and the *Teachable Moment*, found to be so important in the activity analysis of the pilot study. Engagement with *Salient Events* is also extremely personal, as no two students had the same sequence of events or inquiry activity.

9.3. Message for Educators

The ethnographic comparison of the teacher's and students' behavior in the two environments of the pilot study should be of value. Most notable is the difference in the pace and navigation. The real field trip was on a path in the woods where the teacher could control the direction, pace and influence inquiry. It was relatively more linear and structured than the virtual field trip in the computer classroom. In the classroom, the students were exploring independently, and the teacher was following them. The virtual field trip did allow for different frames of reference, especially a bird's eye perspective, allowing fly-up into the forest canopy and a view of the entire terrain. The view enhanced the ability to cover those subjects and incorporate survey knowledge into the classroom discussions.

The study also showed that the operational issues of deployment can be successful in a typical classroom with personal computers and an overhead projector, equipment that is standard in most schools. This would allow future incorporation of virtual-reality field trips into curriculum.

A major finding was the powerful order effect. "Practice makes perfect." Thus, independent of the *Real* or *Virtual Environments*, repeating activity will improve perception, observation, and skill. The activity was a note-taking activity in the form of map annotations, but the implication is that any in-situ activity, ***procedural knowledge***, should show improvement with virtual practice. The findings are very consistent with other virtual reality and simulation training research.

Furthermore, the strong empirical evidence of transfer effects on in-situ activity suggests combination of *Real* and *Virtual* activities for improved richness and increased learning opportunity. The main contribution of this study is a new frame of reference when considering virtual reality field trips. It is to use the real and virtual learning experiences together for maximum impact. Use the virtual field trip to ***prime before*** a real world field trip, to significantly increase learning, and use the virtual field trip after a real world field trip to ***reinforce*** and to allow collaborative sharing. Do not substitute the virtual for the real if the real is available, but use the virtual if the real location is inaccessible.

The findings of the main study should help educators to make choices about classroom-based technology and software. There is no advantage in a *Low Visual Fidelity*, cartoon-based virtual environment if a *High Visual Fidelity* version is also available, *ceteris paribus*. Only the *High Visual Fidelity* virtual environments offer the higher gains in learning. Be aware of possible misconceptions that can also be introduced by *Low Visual Fidelity* software, those that are not based on reality, or those that are based on fantasy. It is a similar choice to one that contrasts the costs and benefits of using a scientific encyclopedia or using science fiction in your curriculum.

Finally, there is evidence that both boys and girls need time to explore. The implication is that at least 40 minutes and up to 60 minutes should be allowed for such virtual field trips, or the gender-clustered learning styles could result in degraded experiences for both.

10. Future Work

This chapter addresses the major future trajectories of this research.

10.1.Future SEEE Tripartite Model Framework Regression Models

The original thesis investigated the relationship between the salience of signals found in the natural environment, real or virtual, a) the VE in terms of the *Visual Fidelity* —or Ambient Array — and *Navigational Freedom* — or the freedom of choice in movement and exploration — and b) *Awe and Wonder* — or the emotional reaction to the experience — as it can cause an event c) *Salient Events* — or of inquiry in the UI — and an intrinsic desire to learn d) *Fact Inquiry* — or drilling down the fact cards. The pilot study ethnographic and empirical results indicated the importance for learning of serendipitous finds along the trail, or *Salient Events*, which have been confirmed, and may be linked to the concept of *Teachable Moments* (Bentley, 1995). The 2x2 ANOVA proved that the factor of *Visual Fidelity*, especially in the HFHN combination, can have substantial impact on *Knowledge Gained* and *Salient Events*.

How can this system be used to isolate the beta coefficients in a causal regression model? Future work will investigate such models and equations. The system design allows for easy isolation of Visual Fidelity as a dichotomous variable (High = 1, Low = 0) for such future regression models. Since we found, in the 2x2 ANOVA, that the factor of Navigational Freedom had no impact, it is not a viable independent variable, so will not be used. However, if a new study, one where the salience of this factor is reduced, shows a significant impact, then it could become a viable independent variable. While Fact Inquiry is positively and significantly, however weakly, correlated to Knowledge Gained, it too could be a viable independent variable and easily investigated. Emotional reactions, especially that of Awe and Wonder, are significantly correlated, although weakly, to Knowledge Gained, and were gathered along a ranked scaled value and thus easy to use in the regression with either dummy variables or converted to a dichotomous variable. Salient Events was a count and so could be investigated, however cautiously, as there would most likely be multicolinearity with the High-Fidelity independent variable. Fitting and modeling such complex relationships will make for necessary and engaging future work.

The following causal model graphically depicts viable relationships for future investigation, such as the causal impact of the variables on *Facts Inquired*, *Salient Events*, *Knowledge Gained*, *Emotions*, and Acts of *Creation*.

Equation 3: Future SEEE Regression Equations

$$\Delta\text{Inquiry} = \alpha + \beta_1(\text{VE}) + \beta_2(\text{UI}) + \varepsilon$$

$$\Delta\text{Exploration} = \alpha + \beta_1(\text{VE}) + \beta_2(\text{UI}) + \varepsilon$$

$$\Delta\text{Knowledge} = \alpha + \beta_1(\text{VE}) + \beta_2(\text{UI}) + \varepsilon$$

$$\Delta\text{Emotions} = \alpha + \beta_1(\text{VE}) + \beta_2(\text{UI}) + \varepsilon$$

$$\Delta\text{Creation} = \alpha + \beta_1(\text{VE}) + \beta_2(\text{UI}) + \varepsilon$$

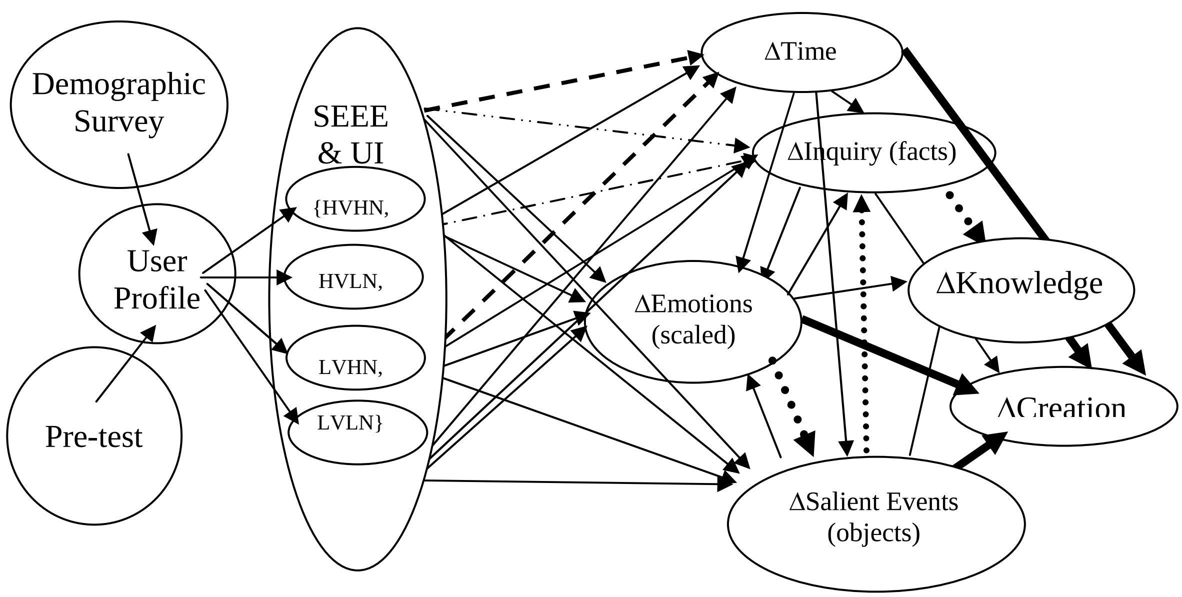


Figure 41: Future SEEE Causal Models

More research and evaluation must be done to understand the potential relationships, as multicolinearity presents a potential problem. The SEEE components consist of a virtual environment (VE), as defined by the *Visual Fidelity Salience Score* and the *Navigational Freedom Score*, and the user interface (UI), as defined by the *Salient Events* and *Fact Inquiry*.

The learning style and *Gender* have to be investigated and developed, especially as part of the user profile. Emotions, such as *Awe and Wonder*, need to be fully investigated in terms of impact and relationships to other variables.

Equation 4: Future SEEE Regression Equations Expanded

ΔKnowledge Gained = $\alpha + \beta_1$ (**VE**) + β_2 (**UI**) + β_3 (**EMOT**) ε

ΔKnowledge = $\alpha + \beta_1$ (user profile-gender) + ε

ΔKnowledge = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + ε

ΔKnowledge = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + ε

ΔKnowledge = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + ε

ΔKnowledge = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + β_5(emotional score) + ε

ΔKnowledge = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + β_5(emotional score) + β_6(creative score) + ε

ΔSalient Events = $\alpha + \beta_1$ (user profile-gender) + ε

ΔSalient Events = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + ε

ΔSalient Events = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + ε

ΔSalient Events = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + ε

ΔSalient Events = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + β_5(emotional score) + ε

ΔSalient Events = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + β_5(emotional score) + β_6(creative score) + ε

Δ**Emotion** = $\alpha + \beta_1$ (user profile-gender) + ε

Δ**Emotion** = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + ε

Δ**Emotion** = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + ε

Δ**Emotion** = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + ε

Δ**Emotion** = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + β_5(emotional score) + ε

Δ**Emotion** = $\alpha + \beta_1$ (user profile-gender) + β_2(SEEE salience score) + β_3(total time - time on task) + β_4(facts/objects) + β_5(emotional score) + β_6(creative score) + ε

10.2. A Tripartite Model Framework of Design Parameters for Spatial Cognition and Situational Learning in Virtual Environments

The SEEE Tripartite Model, shown in Figure 43, represents the bases for future work in understanding the dynamic interaction between the child, the environment and the user interface. The following relationships are of interest.

Equation 5: The SEEE Tripartite Model Formulas

Δ VE -> P(Δ Knowledge | Perception)

Δ UI -> P(Δ Knowledge| Perception)

Δ Knowledge -> P(Δ Perception | VE)

Δ Knowledge -> P(Δ Inquiry | UI)

Δ Knowledge -> P(Δ Creation | ((UI) & (VE))

Δ VE -> P (Δ Knowledge | Perception) is read as "some change in the virtual environment will result in some probability of some change in knowledge, given perception of the virtual environment." (In other words, a surprise in the environment, such as a hawk landing in front of you, will result in your knowing the hawk better, given that you can see.)

∆**UI -> P (∆ Knowledge| Perception)** is read as, " some change in the user interface will result in some probability of some change in knowledge, given perception of the user interface." (In other words, a tool-tip with the text label spelling out the name of the hawk will result in knowing the name "red tailed hawk," given that you can see and read the label.)

∆**Knowledge -> P (∆ Perception | VE)** is read as "some change in real-world knowledge will result in some probability of some change in perception given the virtual environment." (In other words, new knowledge allows you to see more.)

Furthermore, some of these variables may not be discrete values, but may be ranges or sub-ranges, and may also interact with other variables in different dimensions and the corresponding threshold points in these event variables, especially those that make it likely that the child will inquire and learn. These ranges are scaled values, from some minimum value to some maximum value, and may be sensitive to combinations, or convolutions of many signals. The relationships may not be linear, and it presents a complex system of equations to discover and solve.

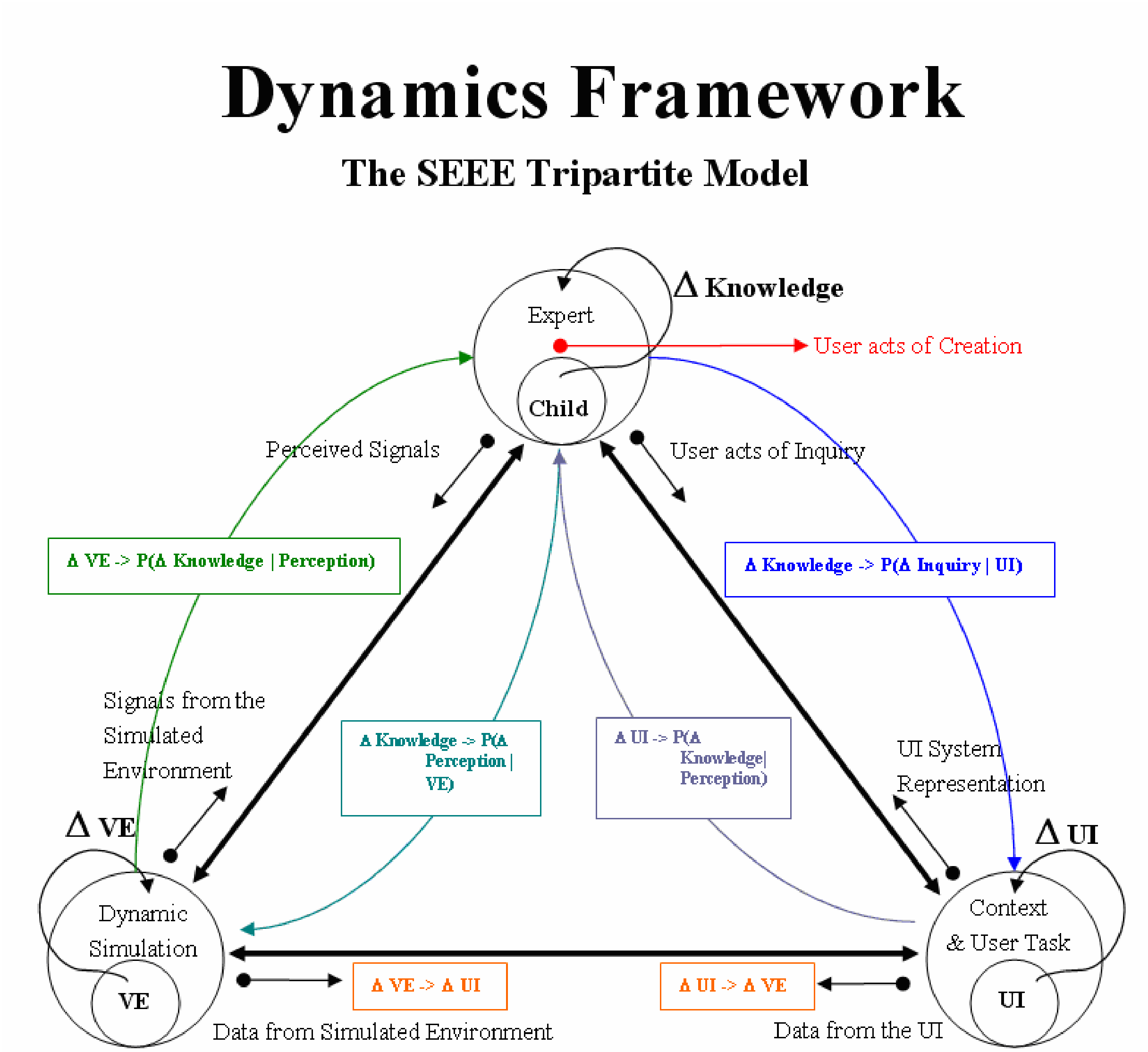


Figure 42: The SEEE Tripartite Model.

Appendix A. Example Activity Analysis of Beechwood Camp

The question is: How can technology be applied to support and extend such an activity?   It is also interesting to note that, even though the lesson was designed to teach about birds, during the walk, the children discovered and were curious about other living creatures in the hike. First, the in classroom instruction was given to the children on how to use the tools. The binoculars were given, and the children tested them. Such an activity may be important for a computer system version too. The fact that the children were walking on the trail is an important metaphor to leverage.   It is quite possible that the location of an event along the trail could be an important method for children to structure newly-acquired knowledge.   Once on the trail, it was the teacher, the trail guide, who pointed out birds for the children to observe. Then she prompted them with some questions. This, too, the context-sensitive questions from a guide or the system's user interface, may be an important event to incorporate into the software.

7/12/04
Beechwood Nature Camp
Lesson: Birds

12:45 PM – 1:30 PM
15 children in a nature camp
1 teacher, 2 assistants
In-class instruction on how to use binoculars

12:45 PM – 1:30 PM
15 children in a nature camp
1 teacher, 2 assistants
In-class instruction on how to use binoculars

Owl was in the far side of the class; teacher instructed children to look at the owl through the binoculars and bring the image into focus by using the lever on the binoculars.

The children all sat on the floor and tried to achieve the task. Many helped each other, and they shared what they saw in each other's binoculars.
Teacher then checked the children's and helped to show them how to use the binoculars.
T: "Are you ready to go?" and passed out a Worksheet – see attached.
T: " Rules on the trail, do not walk and look through the binoculars at the same time, always stop and stand still before you look through the binoculars."

<< They all lined up, divided into two groups and started the hike>>

Outside at the bird feeder, a lot of birds, the teacher stopped and asked, "What do you see?"
C: "Birds."
T: "What kind of birds?"
C: "Turtle Doves, Finches."
T: "How many?"
C "7 Turtle Doves."
T: "What do they sound like?"
C: "Coo coo."
T: "What do they look like?"
C: "Gray and white and black"

C: Other things that got their attention: "I see a chipmunk, I see butterflies, the white ones are most common, I see a potato bug, oh look at this bug on the plant, I see a bee, I see a hummingbird moth."

C: “I see a monarch butterfly.”
C: “No that’s not, that is a swallow tail.”
T: “That’s right that is a swallow tail.”
C “Swallow tail!!” < they chime>

T: “Ok, let’s find more birds, let’s go to the pond.”
<< Teacher led children down the path to the pond, through the meadow; on the way many child-to-child and children-to-teacher conversations occurred. >>

C: “Can we swim in the pond?”
T: “No.”
C: “Is there a boat?”
T: “No boat.”
C: “I was here last year and we had a boat and we went out in it.”
C: “Can we go in the creek?”

<< at the pond>>

T: “I have something to show to you. Look up, through the branches of the tree. What do you see?” <Teacher points up to the tree.>

< Children place the binoculars to eyes and look in the direction the teacher is pointing. >
C: “Where? Where? I don’t see it…”
T: “Up there in the pine tree on the branch to the right, see in the open space?”
C: “Oh, I see it now, it looks like a nest. No it is a snake skin, right?”
T: “Right, it is a snake skin.”

C: < acts very interested and surprised>
C: "Snakes climb trees? Wow!"

< Teacher moves closer to the edge of the pond; children follow and move to the edge and look in. >
C: "I see a fish" <other children cluster and look>.
C: "It is a stick."
C: "There are snails, look."
T: "Ok, now use your binoculars and look for a turtle, they are usually sunning themselves on the logs, any turtles today?

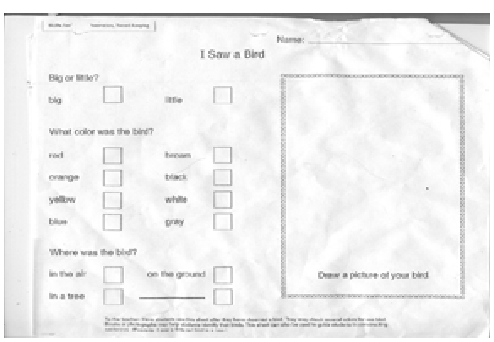
C: "No, can't see."
T: "Today is a raining day, they may not be out" <leading them with a clue>.
C: "It is too cold and raining" <giving answer to why>.

<bull frog croaks>
C: "That's a bull frog!"
C: "I can make that sound, 'BRRR-up, BRR-up' <child makes the sound for a few minutes and others chime in. children even acting like frogs, hopping on the ground>.

T: "Let's find some birds."
< Teacher moves group to the other side of the pond. >
C: "I found a daisy."
C: "It is a Mouse eye daisy"
T: "Oxeye daisy."
C: "Oxeye daisy" <children chime in>.
C: "We have a lot of these in our yard at home"

<Teacher stops at a bird nesting supply spot on the trail.>
T: “Who knows what this is?”
C: “Bird nesting material.”
T: “That’s right. What is in it?”
C: “Paper, string, hair…”
T: “Why is it here?”
C: “To help the birds to build their nests.”
T: “That’s right, you can place one in your yard too to help them” <mental note to change future behavior>.

<<Teacher leads the group along path to the “teaching circle,” a small glen with benches to sit on. One child is scared. She does not want to participate; other children and the teacher try to convince her, talking and reasoning with her. Eventually she joins the group. Teacher passes out a cardboard board to provide stability to write on, then she passes out the worksheets and pencils.>>



Name: ______

I Saw a Bird

Big or little?

big ☐ little ☐

What color was the bird?

red ☐ brown ☐
orange ☐ black ☐
yellow ☐ white ☐
blue ☐ gray ☐

Where was the bird?

in the air ☐ on the ground ☐
in a tree ☐ ______ ☐

Draw a picture of your bird.

T: “Everyone look around, use your eyes, your binoculars, and whenever you find a bird, use your worksheet to record what you see. Is it big or little? What color is the bird? Where was the bird, in the air, or tree? Then draw a picture of the bird as detailed as you can.”

<<Children did exercise and moved on to a new camp activity at 1:30>>

7/13/04
Beechwood Nature Camp
Lesson: Plant: Pre-Camp spontaneous lesson - Mother, Scott and Child

C: "Look, the medicine plant, the one that cures toothaches," <child pulls the plant from the ground – was not suppose to.>

P: "Do you mean Yarrow?"
C: "Yes that one"
P: "I don't think so. It may be a wild Carrot, let's go ask Scott, he is the expert."
C: "Look what I found, is it a Carrot or Yarrow?"
S: "I think it may be a Wild Carrot, or it may be Poison Hemlock. Don't eat it. It is not Yarrow. It is really difficult to tell, if you don't have the flower. The flower can really help you to identify the plant. Come with me to the library, we can look in the field guide to edible wild plants"

<<Scott, child, and parent follow to the library>>

Scott pulls out *A field Guide to Edible Wild Plants* a reference book.

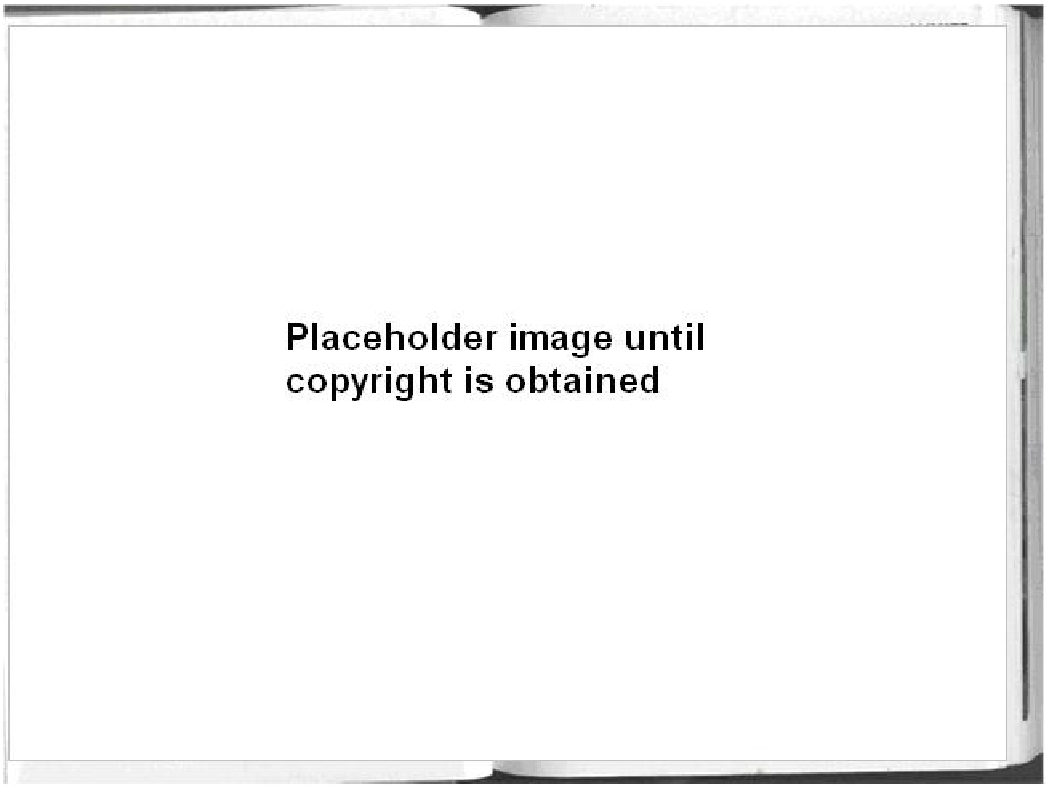


Figure 43: ***A Field Guide to Edible Wild Plants, of Eastern and Central North America*** **(L. Peterson, 1999).**

"Both Wild Carrots, Yarrow and Hemlock are part of the same family. We can all see the leaves are very similar, and we need the flower to identify with certainty." <Child then searches for a flowered version.>

Once brought back to Scott. "Are the leaves the same?"
C: "No these are longer and skinnier."
T: "Which plant does it look like? The flower?"
C: "This is the Yarrow!! This is the medicine plant!!" <Note that this book does not contain the aspirin-like qualities of the plant only that you can make a tea from it.>
P: "The other plant is then either a Wild Carrot or Poison Hemlock."
T: "You should go wash your hands, just in case."

Appendix B. Example of the Current Paradigm of CBT

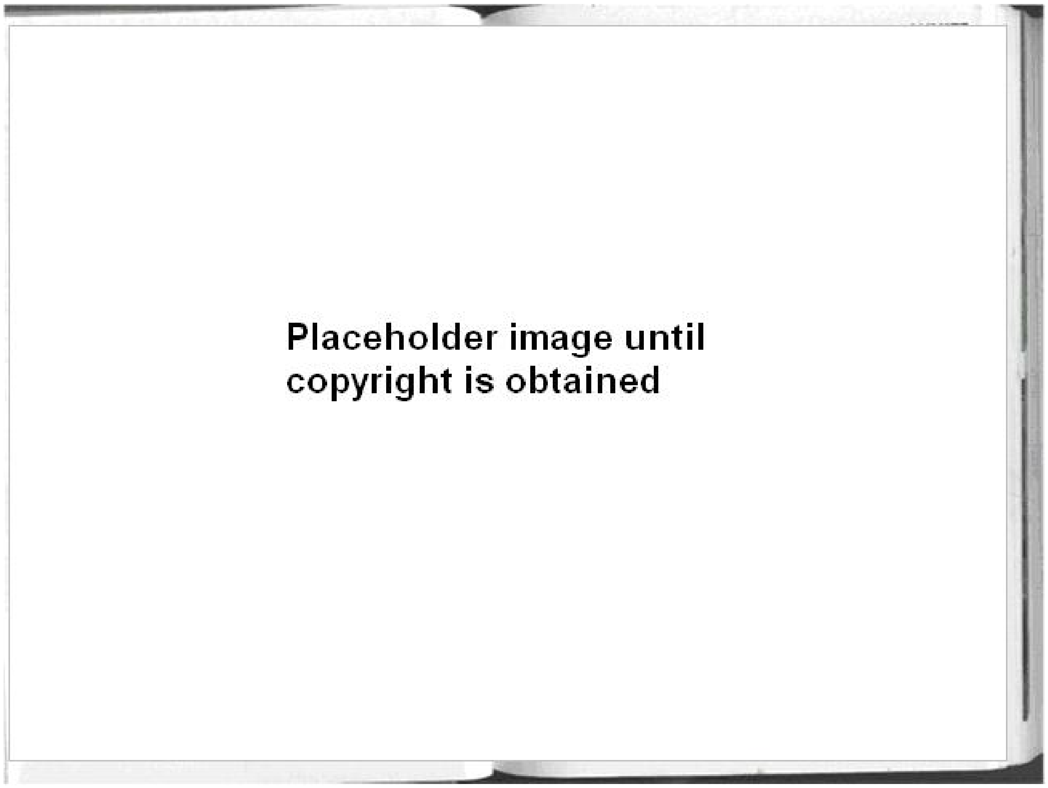


Figure 44: A screen capture from the *Ecology* (*Ecology Interactive CD-ROM from the Discovery Channel School for Life Science Education of grades 6-12. [Discovery, 2006]*).

Appendix C. Example of Science Education Embedded in a Story

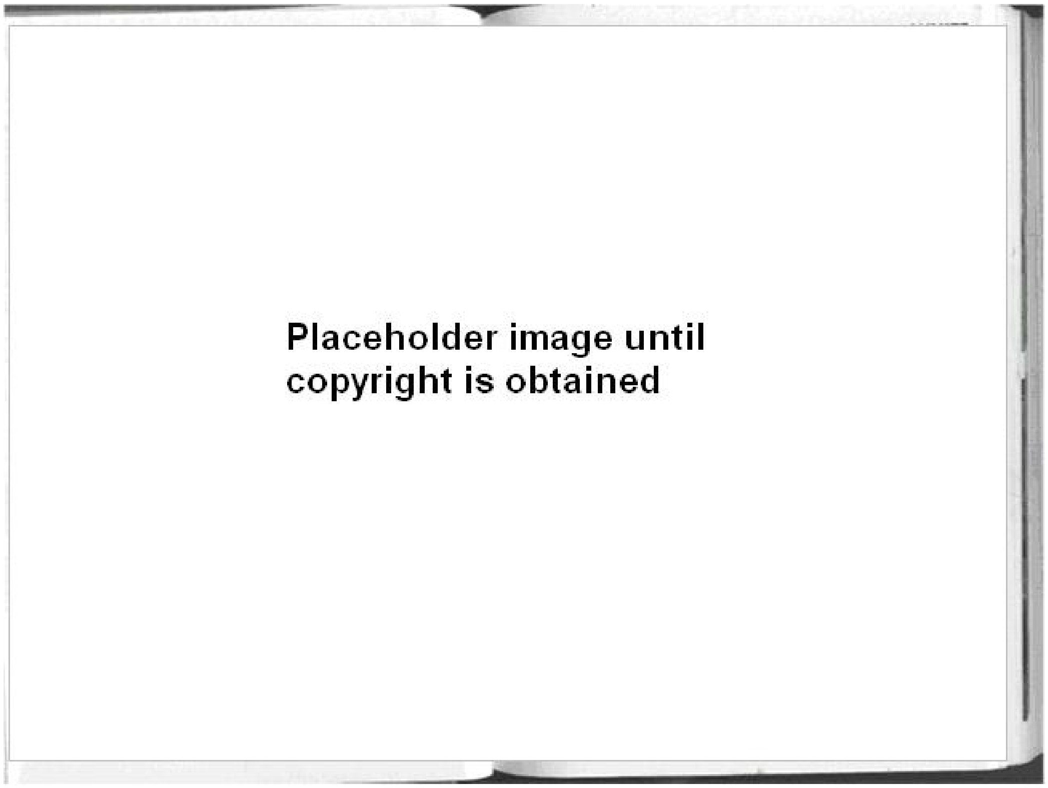


Figure 45: A page from the book *The Magic School Bus Takes a Dive: A Book about Coral Reefs* (Cole & Degen, 1998).

Appendix D. Example of Science Education in an Annotated Reference Book

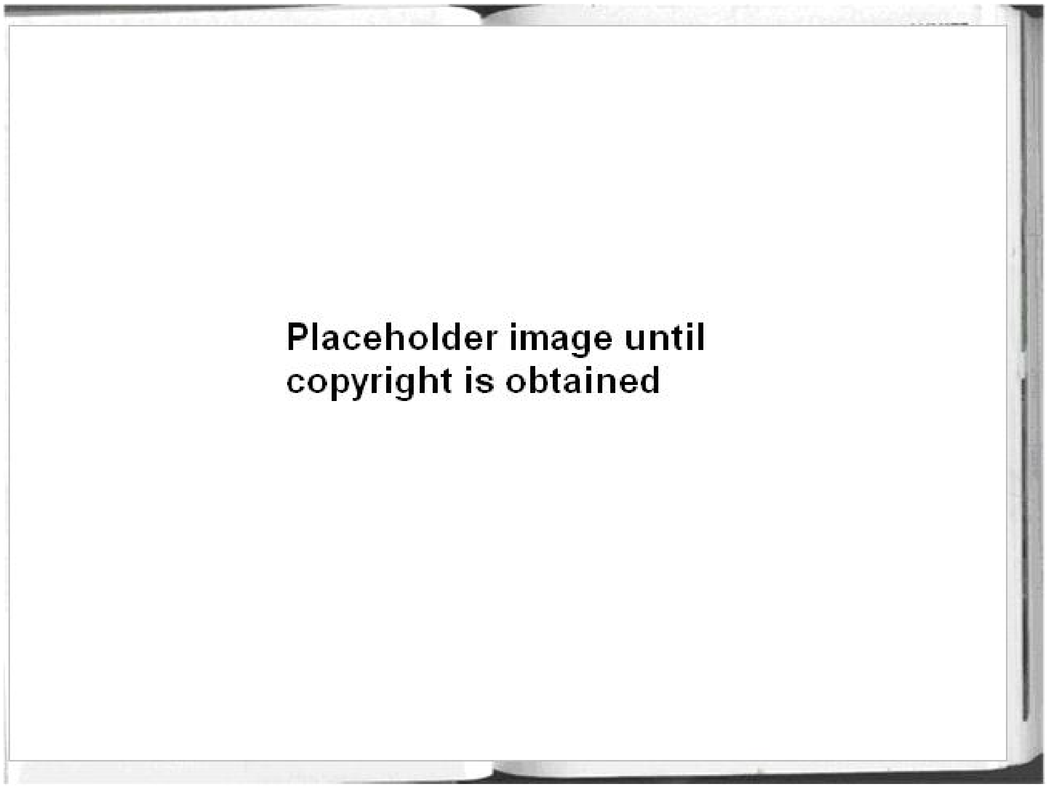


Figure 46: A page from *DK Eyewitness Books: Ecology* (Pollock, 1993).

Appendix E. Demographic Survey for Study One

Demographic and profile data of subjects will be gathered in a survey. After the subjects have agreed to participate, have signed the appropriate IRB release forms, an appointment reminder to come the experiment will be mailed (emailed and phone messaged) to them. It is expected that the parent will help the child to fill out the demographic survey quickly, and it is expected to take five minutes.

1)	Gender	(male, female)
2)	Neighborhood?	(Fox Chapel, O'Hara, Indiana, Blawnox, Sharpsburg)
3)	Beechwood Camp Exposure	(Yes, No)
4)	Number of Beechwood Field Trips Attended	(1-10)
5)	Number of trips to Nature Parks in the last year?	(1-10)
6)	Have you been to Trillium Trail?	(Yes, No)
7)	Do you like Flowers?	(1-10)
8)	Do you or your parents' garden?	(Yes, No)
9)	Do you know how to use a computer?	(1-10)
10)	Do you have a computer at home?	(Yes, No)
11)	Do you have a video game at home?	(Yes, No)
12)	About, how many hours per week do you spend on the computer?	(1 – 10)
13)	About, how many hours per week do you spend playing video games?	(1– 10)
14)	About how many hours per week do you spend playing outside?	(1 – 10)
15)	Do you like nature?	(1-10)

Male = 0, Female = 1
Fox Chapel = 5, O'Hara = 4, Indiana = 3, Blawnox = 2, Sharpsburg = 1

Yes = 1, No = 0
Score from 1 -10
Total score will be used as a proxy for a weighted User Profile. Range is (0 – 85).

Appendix F. For the Post-Test for Study One

The pre-test questionnaire is expected to take only 10 to 20 minutes. It is expected to cover the following rubric. Each fact, concept and value is equally weighted for one point. Concepts and values are graded by content on a bell curve distribution. Test Range is 0 -100 possible points.

Evaluation Rubric

Facts (73 points)

What is a forest?
What are the three main parts of a forest?
What are the three things plants need to live?
Name all of the trees that you know – how are they different?
Name all of the flowers you know.
How do you identify flowers?
What are the parts of the flower and what are their functions?
Do you know of any plants you can eat?
Do you know of any plants that are used for medicine?
Do you know of any plants that are poisons?
What is so special about the mayflower fruit?
How can you tell how old a tree is? Do you know what the oldest tree is in the Trillium Trail forest?

Concepts (17 points)

What is a watershed?
What makes valleys?
What is pollination?
What is photosynthesis?
What is the purpose of a dead old log?
What is a habitat?
What is a niche?
What is a symbiotic relationship?
Give an example of form and function in nature.
Can you explain how and why non-living and living things are connected?

Beliefs (10 points)

Why are forests important?
Why are flowers important?
Why is a watershed important?
If you owned Trillium Trial, and someone wanted to buy it, what percent would you charge?

Pre-test Questionnaire for Study One

1) What Trees do you know? (Any from Trillium Trail?)

____
____
____
____
____

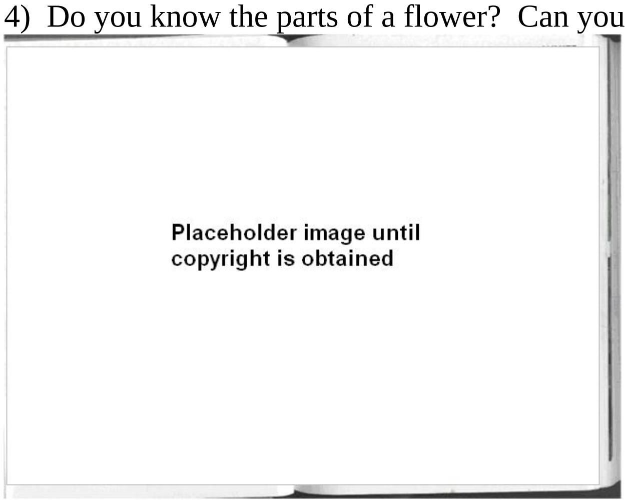
2) What bushes do you know? (Any from Trillium Trail?)

____
____
____
____
____

3) What Flowers do you know? (Any from Trillium Trail?)

____
____
____
____
____
____
____
____
____
____
____

4) Do you know the parts of a flower? Can you draw a line from the name to the part?



5) What does a plant (flower, tree or bush) need to live? Can you think of three or more things?

____

____

____

6) Why does a flower bloom?

____

____

7) Naturalists use many different terms to describe the shapes of leaves. Can you draw a line from the name to the type?

8) Draw a picture of your favorite plant (tree, bush, or flower), and label all parts that you know.

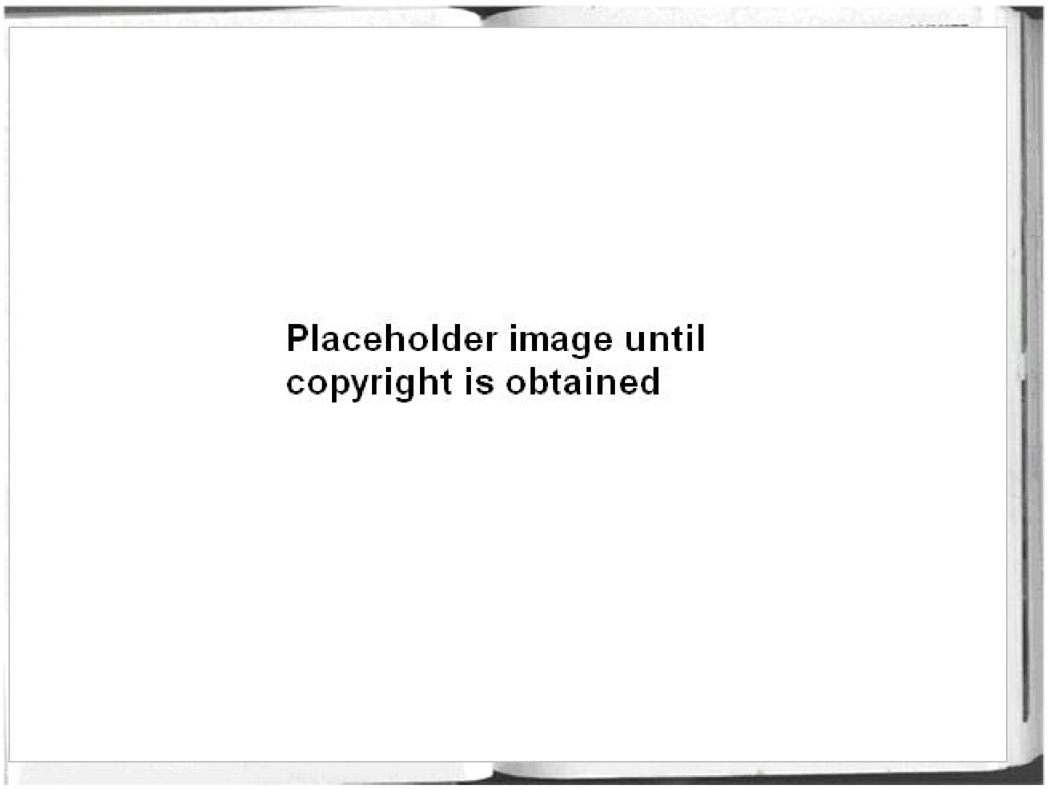
9) Can you draw a line from the word to the parts of the forest?

10) The Forest "Apartment Building" has a least four levels, or niches that support different communities. Can you name the levels of a forest? What lives in, and what happens in each level?

Niches? Part of the forest.	What lives here?	What happens here?
____________________	______________	______________
____________________	______________	______________
____________________	______________	______________
____________________	______________	______________

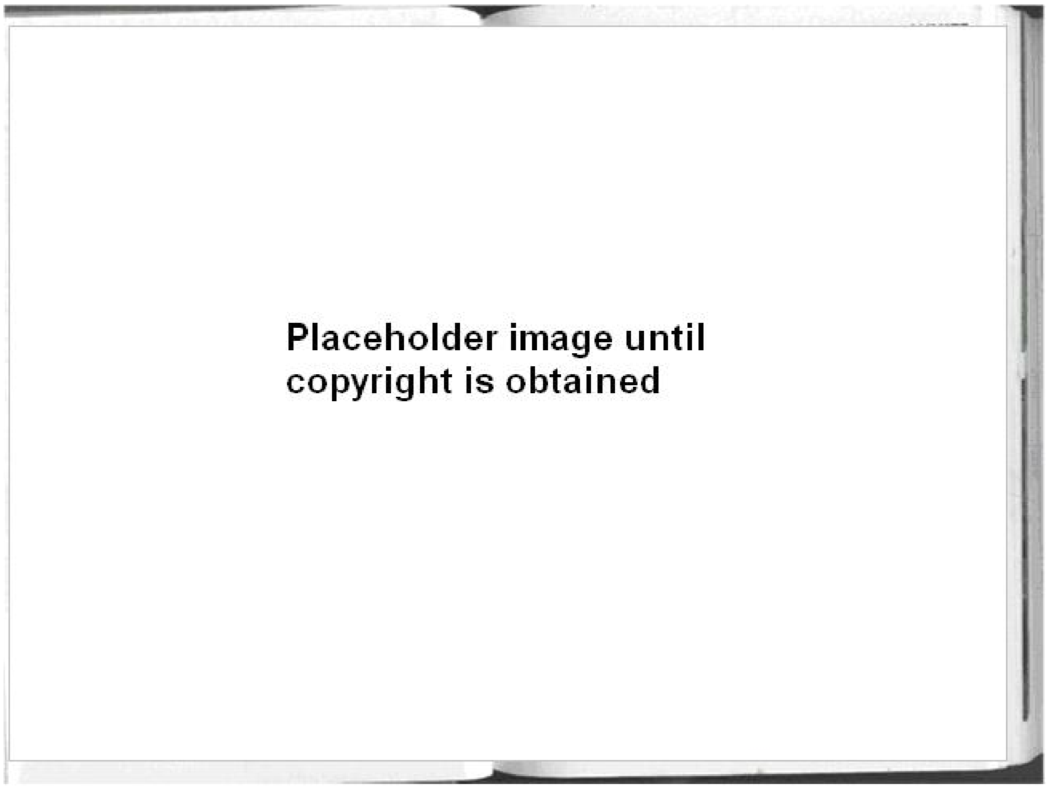
11) There are different places where different plants like to live. Draw a line from the words to the correct place on the image.

The Topography of the Appalachian Plateau
Form and Function

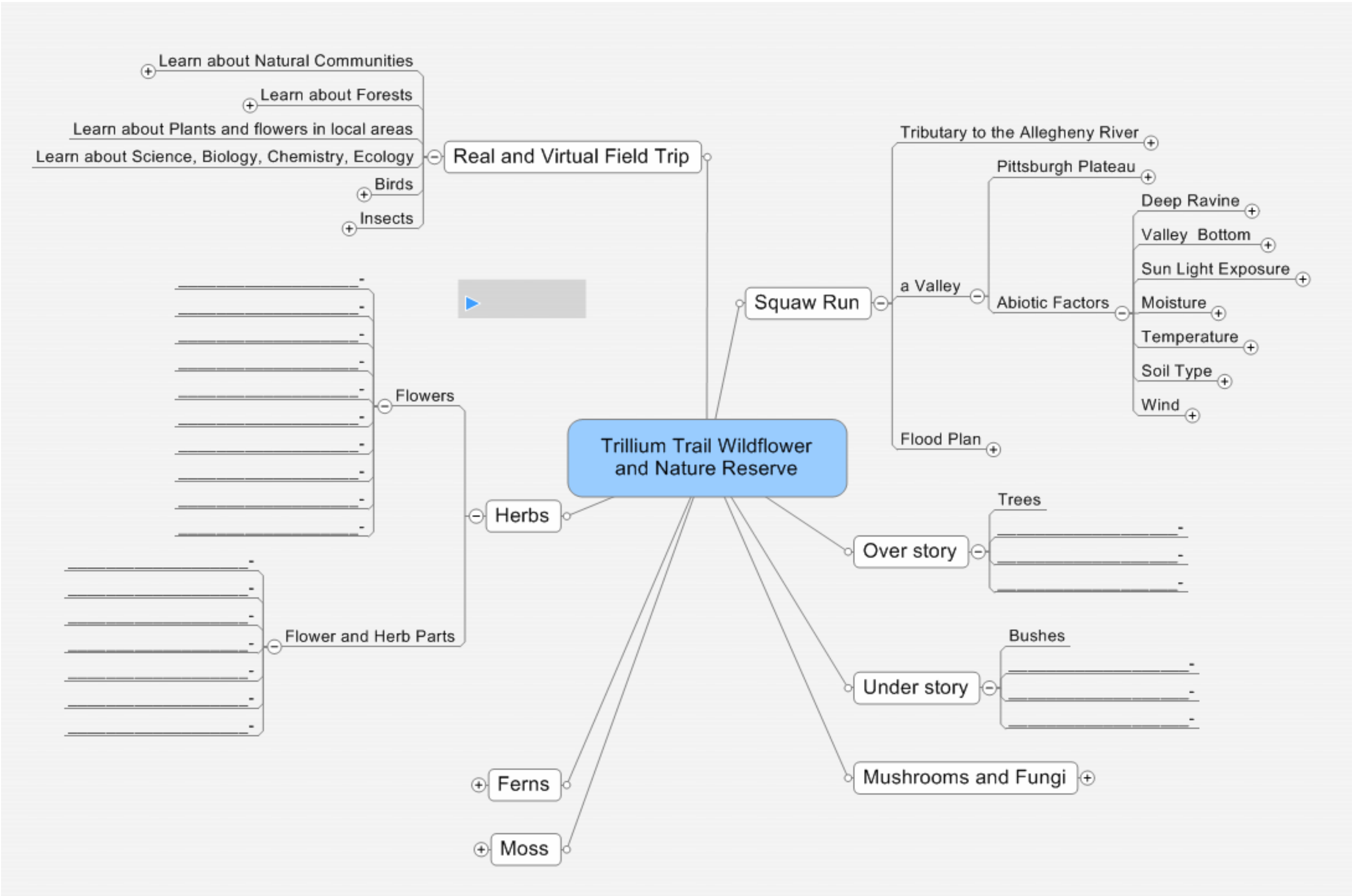


There are different places where different plants like to live. Draw a line from the words to the correct place on the image.

The Topography of the Appalachian Plateau
Form and Function

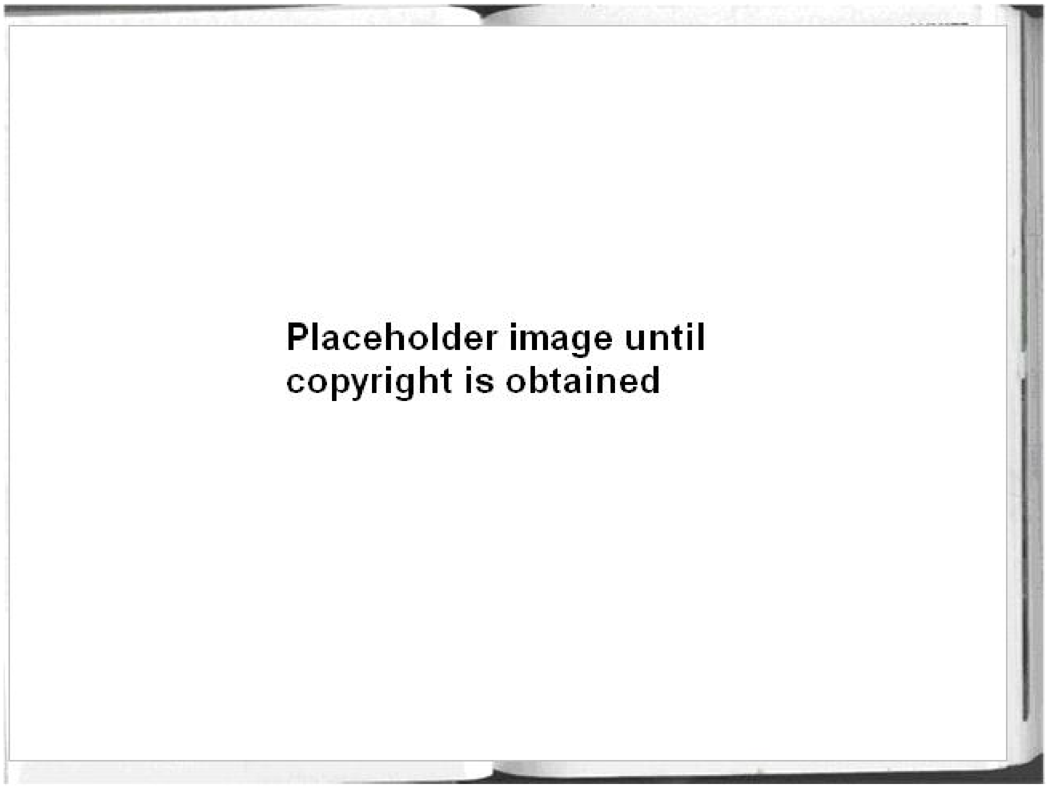


12) Make a Web (writing web) of the forest community and wildflowers; show any interesting facts you know.


Trillium Trail Wildflower and Nature Reserve
Real and Virtual Field Trip
Learn about Natural Communities
Learn about Forests
Learn about Plants and flowers in local areas
Learn about Science, Biology, Chemistry, Ecology
Birds
Insects
Squaw Run
Tributary to the Allegheny River
a Valley
Pittsburgh Plateau
Abiotic Factors
Deep Ravine
Valley Bottom
Sun Light Exposure
Moisture
Temperature
Soil Type
Wind
Flood Plan
Herbs
Flowers
Flower and Herb Parts
Over story
Trees
Under story
Bushes
Mushrooms and Fungi
Ferns
Moss

13) Write a short story about your favorite flower or park, and tell me why.

14) The Web of Life. Show the Connections of the land, water, plants, and flowers. Place all of the facts, concepts, and values you can think of here on the web and show the connections.



15) Do you think green spaces are needed? Is this just some trees and dirt, or is Trillium Trail a special place? (You may want to write a letter to the local government officials).

Appendix G. Materials for Study Two

Pre-Experience User Profile Survey

1)	Gender	(male, female)
1)	Neighborhood?	(Aspinwall, Fox Chapel, O'Hara, Indiana, Blawnox, Sharpsburg)
2)	Number of Beechwood field trips attended	(1-10)
3)	Number of trips to nature parks in the last year?	(1-10)
5)	Have you been to Trillium Trail?	(Yes, No)
6)	Do you like flowers?	(1-10)
7)	Do you or your parents garden?	(Yes, No)
8)	Do you know how to use a computer?	(1-10)
9)	Do you have a computer at home?	(Yes, No)
10)	Do you have a video game at home?	(Yes, No)
11)	About how many hours per week do you spend on the computer?	(1 – 10)
12)	About how many hours per week do you spend playing video games?	(1– 10)
13)	About how many hours per week do you spend playing outside?	(1 – 10)
14)	Do you like nature?	(1-10)

Pre- and Post-Test and Grading Rubric Key

Pre-test = total points awarded
Post-test = total points awarded

Concepts

1. What is an Ecosystem?

1 is when all living things interact and depend on each other for life – interconnected system of nature and all of life, plants to plants, plants to animals, animals to animals and all abiotic and biotic forces.

2. What is a habitat?

1 is a place where a living organism plant or animal comfortably lives and all of their needs are met

3. What is a niche?

1a habitat where organisms can co-exist without competition – it is the organisms role or job

4. What is a forest?

1 a large group of trees

5. What is a watershed?

3 – 1 a divide – a body of land that is defined by its highest points. 1 it functions much like a natural basin to capture the rain water and flows into a body of water at its lowest point. 1Many watersheds are interconnected eventually draining into the ocean

6. What is a plateau?

2 a land formation that is a high flat mountain top 1 – dry, less nutrient-rich soil

7. What is a valley?

1 a land formation that is a depression 1 – wet and nutrient-rich soil

8. What is pollination?

5 - 1 is when an animal, such as a bee, butterfly or hummingbird, 1 gets nectar 1 carries pollen from one flower to another of the 1 same species and then the flower can create 1 fruit and seeds.

9. What is photosynthesis?

5 - 1 the process that all green plants do to create food – 1 the process of converting 1 sun energy, water, carbon dioxide into oxygen and 1 sugar 1 it occurs in the chlorophyll in the leaves

10. What is plant respiration?

1 how plants breathe – they passively take in 1 carbon dioxide and oxygen and release oxygen

11. Where do plants store their energy?

1 roots

12. What is adaptation?

1 is when an organism changes in order to survive better in its habitat or an adaptation is a part/feature to help the organism survive.

13. Can you explain the connection between non-living (Abiotic) and living things (Biotic)?

3 lots of time living things depend on non-living things, such as water, which is Abiotic, and air, which is Abiotic, or homes, such as dirt, rock, so air, water and shelter, all life which is biotic depends on the Abiotic things

14. What is a symbiotic relationship?

1 co-operative

Facts

15. Name all of the wildflowers you know.
1 point for each that is in the SEEE system

16. Name all of the wild bushes you know.
1 point for each that is in the SEEE system

17. Name all of the wild trees that you know.
1 point for each that is in the SEEE system

18. What are the things plants need to live?
7 - sun, water, nutrients in the soil, and air (carbon dioxide and oxygen) + space, temperature

19. What are the main parts of a forest?
4 - forest floor, herb layer, shrub layer, canopy

20. Can you think of some words used to describe the shapes of leaves?
1 for each - lobbed, whorled, toothed, smooth, parallel, alternate, opposite, symmetrical, oval, needles, sisal, heart, basil

21. Why does a flower bloom?
4 - 1 to attract pollinators 1 to get pollinated, and 1 to make fruit / seeds 1 – to give beauty (art)

22. How do you identify flowers?
1 for each - color, number of petals, the shape of the leaf, height, where it grows, smell, time of year, seed pod, roots - feel

23. What are the parts of the flower?
__ Leaves __ Stem __ Petal __ Stamen __ Sepal __ Anther __ Filament __ Style __ Pistil
__ Stigma __ Ovary __ Pollen __ Roots __ Seed

24. Do you know of any wild plants you can eat?
1 point for each that is in the SEEE system

25. Do you know of any wild plants that are used for medicine?
1 point for each that is in the SEEE system

26. Do you know of any wild plants that are poisons?
1 point for each that is in the SEEE system

27. What is so special about the Mayapple? Umbrella plant?
1 for each – blooms only after 2 years old, when it has two leaves, the fruit is a favorite of the turtle, the fruit is edible when ripe, the rest of the plant is very poisonous, and the chemicals in the plant are used to help cure skin cancer, used as a crop insecticide, fruit is phosphorescent – glows in the dark

Beliefs

28. Why are forests important?

29. Why are flowers important?

30. What is the purpose of an old dead log?

31. Why is a watershed important?

32. If you owned Trillium Trial, and someone wanted to buy it, what would you charge?

33. Draw a picture of a "Forest Ecosystem."

Post-Experience Attitude Survey:

Please answer the following questions:

7. What did you enjoy the most in the Virtual Field Trip?

8. What did you dislike the most about the Virtual Field Trip?

9. How would you improve the Virtual Field Trip?

10. What was it that you learned?

11. Describe your ideal Virtual Field Trip.

12. Describe how you felt in the Virtual Field Trip.

Please place "X" next to the words that describe your attitude or opinion best.

*Example: I was able to **fly** in the Field Trip.*
___ Not at all ____ Somewhat ___ Average ___ Mostly ___ A great deal

1. I was able to **explore** more in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

2. I was able to **inquire – ask more questions** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ___ A great deal

3. I was able to **learn more** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

4. I experienced **heighten curiosity** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

5. I experienced an **emotional sense of calm** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

6. I experienced **excitement** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

7. I experienced **awe and wonder** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

8. I experienced **frustration** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

9. I experienced **disinterest** in the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

10. I want to **create** something like what I experienced from the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

11. I want to **share** this experience with my friends.
___ Not at all ____ Some what ___ Average __ Mostly ____ A great deal

12. Did you want to **re-experience** the Field Trip.
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

13. Did you experience a sense of **presence or of "being there"** in the Field Trip?
___ Not at all ____ Somewhat ___ Average ___ Mostly ____ A great deal

14. Did you experience a sense of **beauty** in the Field Trip?
___ Not at all ____ Somewhat ___ Average ___ Mostly ___ A great deal

Appendix H. for Post-Experience both Study One and Two

Microworlds

In a post-experience follow-up, the researcher will ask them if they want to stay and build their own virtual world, or a simulation of Trillium Trail. This is much like a diorama creation activity (Harrington, MCR 2006b).

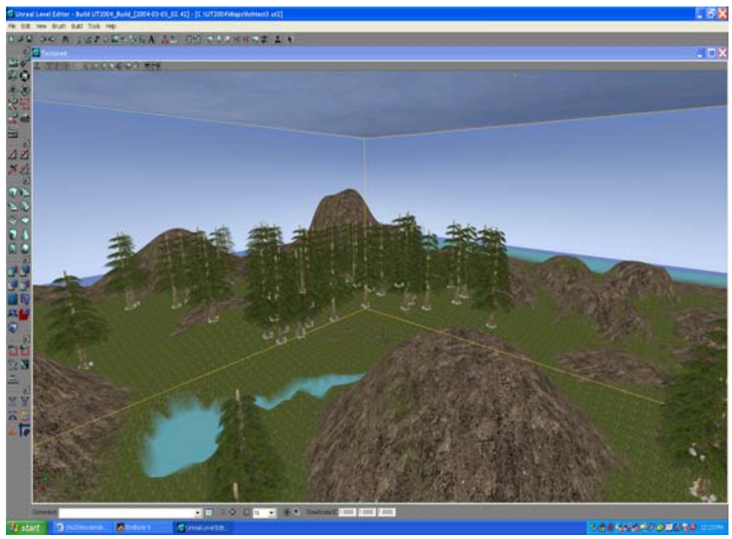


Figure 47: An example of a diorama and a screen capture of a nine year-old child's microworld creation.

If the child wants to create a world, then the researcher will give them a short (10-minute) training session. The video will be set up to record this activity. The child may create anything they want.

- The **creative assessment score** of the micro-world will be set to the quality of the model. (0% -100%)
- 20% for the execution of model
  - Size / complexity (use the model's file size)
  - Geographical features present (valley, stream, plateau, forest, meadows, waterfall, tributaries, ponds or pools)

    - Correct context placement of plants (high / low, sunny / shady, wet / dry, forest niche)
- 20% Correctness – if they explain their reasoning in conversation to their parent.
- 30% Uniqueness – How different, or is it a copy of the SEEE?
- 30% Personal value? – Do they value their creation?

The parents will be instructed to prompt their children to tell them about their activity – what they are doing, and why. If there was not a lot of discussion during the creation process, the researcher may, once the child is finished, ask that she explain it to her parent. It will be interesting to see what choices the child makes, as well as her motivation behind those choices. This activity is expected to take 20 to 40 minutes.

Appendix I. Literature Review Tables

Projects Summary

Simulated Ecological Environments for Education

Table 3. Projects Summary

	Overview						*Educational Dimension*		*Demographics*
	Name	Lab	University / Center	Researchers	Date	Description	Educational Goals	Standards Used	Subjects / users
1	**The KidsRoom Project**	Media Lab	MIT	Bobick, Intille, Davis, Baird, Pinanez	1996 to 1999	Ubiquitous, interactive play space, narration			Elementary and researchers
2	**NICE Project**	EVL	Unv. Illinois, Chicago	Roussou, Johnson, Leigh, Vasilakis, Barnes,	1997	Collaborative	Qualitative - environmental concepts and constructivism, collaborative learning and narrative development skills		Elementary, teachers and researchers
3	**NewtonWorld**		George Mason Univ., Univ. of Houston	Dede, Salzman, Loftin, Ash	1994 to 1999	Science Simulations and Visualizations	Quantitative - correct misconceptions on Newtonian Physics: kinematics and dynamics on motion		30 High school students physics educators and researchers
4	**MaxwellWorld**		George Mason Univ., Univ. of Houston	Dede, Salzman, Loftin, Ash	1994 to 1999	Science Simulations and Visualizations	Quantitative - exploration of electrostatics and Gauss Law		High school students, physics educations and researchers
5	**PaulingWorld**		George Mason Univ., Univ. of Houston	Dede, Salzman, Loftin, Ash	1994 to 1999	Science Simulations and Visualizations	3D molecular structures visualized		High school students, physics educations and researchers
6	**Global Change World**	College of Education, HIT Lab	University of Washington	Jackson, Taylor, Winn	1997 to 2000	Ecology, Global Warming	Complexity, cause and effect, observational skills, data gathering skills, scientific approach, hypothesis testing		Ninth grade students
7	**The Virtual Reality Gorilla Exhibit**	Graphic, Vis. & Usability Center	Georgia Institute of Technology; University of Georgia, Indiana University, SUNY college at Oneonta	Allison, Wills, Bowman, Wineman, Hodges, Hay, Barnett	1997 to 2000	To teach children about the vocalizations, social structures and habitat of the gorilla	Children adopt the personal of an adolescent gorilla "avatar"		General public all ages (7 to 18 yr.old)
8	**The Round Earth Project**	EVL	University of Illinois at Chicago	Johnson, Moher, Ohlsson, Gillingham	1999 to 2000	Mission control and model of the earth and an asteroid	Impact of VR on changing the mental models of very young children. Help children to understand the concept of a round versus flat earth and conceptual change. Normal understanding take years, with this treatment statistically significant improvement occurred with treatment	Based on Vosniadou's original study 1992	Second and third grade students
9	**The Field: v1: 1999**	EVL	University of Illinois at Chicago	Johnson	1999 to 2000	Integrate VR into school curriculum, grew out of the Virtual Ambients Project - plants, flowers, landmarks and	VR for education in science, data gathering and pattern discovery	National standards for science education	Kindergarten through sixth grade students at a public elementary school
10	**The Field: v2: 2001**	EVL	University of Illinois at Chicago	Johnson, Moher, Ohlsson, Leigh,	2001	ibid	VR for education in science, data gathering and pattern discovery and science inquiry and methodology of data collection	ibid	Kindergarten through sixth grade students at a public elementary school
11	**The Field: v2a: 2001**	EVL	University of Illinois at Chicago	Johnson, Moher, Ohlsson, Leigh,	2001	ibid	Explore and take notes and survey a space	ibid	First grade
12	**The Field: v2b: 2001**	EVL	University of Illinois at Chicago	Johnson, Moher, Ohlsson, Leigh,	2001	ibid	Search for different types of plants and draw pictures of them	ibid	Second grade
13	**The Field: v2c: 2001**	EVL	University of Illinois at Chicago	Johnson, Moher, Ohlsson, Leigh,	2001	ibid	Observe growth rates (see six months of growth over two days)	ibid	Forth grade
14	**The Field: v2d:2001**	EVL	University of Illinois at Chicago	Johnson, Moher, Ohlsson, Leigh,	2001	ibid	Correlations between plants	ibid	Sixth grade

15	**The Field: v3: 2002 (aka Bee Dance)**	EVL	University of Illinois at Chicago	Johnson, Moher, Cho, Lin, Haas, Kim	2002	Observe the gesture language of bees, record behavior, collaborate to decipher the	Inter species relationships of plants, insects and pollination and the Bee Dance	AAAS American Association for the Advancement of Science	ibid
16	**The Field: v4: 2003 (aka My World)**	EVL	University of Illinois at Chicago	Cho, Moher, Johnson, Edelson, Russell	2003	Addition of GIS / simulated GPS and Trace view - data exploration path on a map	Individual data gathering, collaboration, combining class data, patters, correlations, cause and effect, hypothesis testing to increase capability to plan and conduct scientific investigations, teach correlations, linear interpolation and extrapolation and distribution.	National standards for science education	ibid
17	**The Field: v5: 2004**	EVL	University of Illinois at Chicago	Johnson, Moher, Cho, Ederlson, Russell	2004	Addition of GIS / simulated GPS and Trace view - data exploration path on a map and laptop visualization	ibid	ibid	ibid
18	**Nerve Garden**			Damer	1997	biologically inspired virtual world programmed to be delivered over the Internet	Simulate a virtual terrarium and to allow users to create their own plants and let them grow in a persistent VE	VRML, Internet, Browser, Java	SIGGRAPH 1997 demographic
19	**Plants and Biological Simulations**	Algorithmic Botany	University of Calgary, CA	Prusinkiewicz	1980 - present	Plants modeled and simulated as biological agents			
20	**Virtual Kelp Forest**		Naval Postgraduate School and the Monterey Bay Aquarium	Brutzman	1998 - 2002	Teach computer graphics programming class	Teach programming in Univ. Class, and mission of the Aquarium		General public all ages, research scientists, primary, secondary and college age students
21	**The Virtual Oceanarium**		Fraunhofer Institute for Computer Graphics, Lisbon Oceanarium, Portugal & Fraunhofer IDG	Frohlich	2000	Built for the World Fair Expo '98 (simulation of 25 species and about 1,000 individual creatures and plants)	Mission of the Aquarium, to provide education to the general public		General public, all ages
22	**SciCentr and BioLearn**	Cornell Theory Center, Univ. of California, Santa Cruz	SciCenter (Cornell Theory Center) & BioLearn (LifeLearn bioregional	Corbit, DeVarco	2000	Comparison study of two desktop VE internet based systems	Multi-user virtual museum and science center, educational goals are consistent with the parent organization		
23	**Multi-User Virtual Environment**	MUVEs	Harvard, Graduate School of Education	Dede, Nelson, Ketelhut, Clarke, Bowman	2003	"River City" an Internet, multi-user VE for the study of classroom-based situated	Students with English as a second language, and from lower SES could benefit from VE. Collaborative & Situational in class learning with Chemistry Simulation		162 Boston Public Schools
24	**Multi-User Virtual Environment**	MUVEs	Harvard, Graduate School of Education	Dede, Clarke, Ketelhut, Nelson, Bowman	2005	ibid, additional concepts of ecology and biology	Students with English as a second language, and from lower SES could benefit from VE. Collaborative & Situational in class learning with Biology Simulation		300 Boston Public Schools and the Milwaukee-area classrooms
25	**Models and Simulations of Cell for Biology**		The Virtual Cell (North Dakota State University) and Boston Science Museum (Brown University	each project date		Model and simulation of the cell, resulting simulation and visualizations and functions surrounding photosynthesis	Process and declarative knowledge		

26	**Virtual Environment in Biology Teaching**		Department of Primary Education, University of Ioannina, Greece	Mikropoulos	2003	Teach plant cell biology, process of photosynthesis. Fully interactive 3D model of plant cell and organelles. Magnified cell	Teacher interacts with the virtual cell model to create / cause photosynthesis		37 teachers participating in an in-service.
27	**Virtual Big Beef Creek**	HIT Lab	University of Washington	Campbell, Collins, Hadaway, Hedley, Stoermer	2002	3D geo-visualization of Big Beef Creek, an Estuary on Washington State's Olympic Peninsula; 3D model built from sensor gathered data via the PRISM project	Teaching Ocean Sciences (GPS and GIS and sensor data gathering) and other related Geo-Sciences, complex scientific processes; marine and coastal environments of Pacific North West		College students
28	**The Virtual Field Station**		National Grid for Learning, MEDASSET the Mediterranean Association to Save the Sea Turtles, University of Exeter, King's College Taunton	Poland, laVelle, Nichol	2003	Compared learning from a real field trip to a virtual field trip, virtual plot study of a fantasy beech where Mediterranean Sea Turtle lay eggs and the human impact :not VE, hyper media, intelligent tutor	Topics in biology, scientific procedural knowledge in how to conduct a plot study	A-Level Biology : ORD Examining boards; compared test scores of treatment group to previous A-Level test scores from a previous class	Independent secondary school of approximately 550 students, 10 students in final year taking A-level biology; the subjects ranged widely in their GCSE scores
29	**MagicBook**	HIT Lab	University of Washington, Hiroshima City University, Sony Computer Science Lab	Billinghurst, Kato, Poupyrev	2001	AR system, flying into book, MR and a wide variety of subjects - like computer generate "pop			
30	**MagicLenses**	HIT Lab NZ	University of Canterbury, NZ	Looser, Billinghurst, Cockburn	2004	Magnifying glass metaphor used to look at objects, the MagicLenses allows users to virtually use a virtual lenses as a tool for scientific visualization or			
31	**eyeMagic Book**	Hit Lab NZ	Centre for Children's Literature, Christchurch College of Education and HITLab (NZ) and UltraLab	McKenzie, Darnell	2003	Five day workshop on constructing AR Storytelling	Ten 10-14 years old children, with help were able to construct their own 3D models and stories		
32	**The Ambient Wood**	Equator IRC	Interdisciplinary Research Collaboration: Indiana Univ., EPSRC: Bristol, Nottingham, RCA, Southampton, and Sussex Univ.	Weal (2003), Michaelides, Thompson, DeRoure; Rogers (2005), Price, Randell, Fraser, Weal, Fitzpatrick	2003 to 2005	A "field trip with a difference": ambient, augmented real world environment (Sussex, UK wood) in nature, to provoke children to stop, observe, wonder and	Children s hypothesized and experimented with biological processes taking place in the wood, gathered data, analyzed and collaborated; goal to promote reflection		16 children worked in pairs, eight pairs of 11 to 12 year olds

33	**Digital EE**	Graduate School of Informatics	Kamigamo Experimental Forest, Kyoto University & Kagawa University	Okada, Tarumi, Yoshimura, Moriya	2001 to 2003	Collaborative AR and VE environment to support multiple discussions, negotiations and learning acts among diverse people	Communication, co-navigate, co-inquiry in a real and virtual shared space for "voluntary" or intrinsic desire to learn about nature and the environment		Ten subjects, most female, positive about environmental interests and experienced with computers
34	**Interactive Art**		Arts Electronica Center, Museum of the Future in Linz, Austria; and ALTERNE "Alternative Reality in Networked Environments"		2005	Innovative use of CAVEs in Museums and Art / tech consortium pushing the boundaries of art and technology for creative	experimental, situational art and technology		Gerneral public
35	**The Tent**	Mixed Reality Laboratory & The Interact Lab	Interactive Institute Tools for Creativity Studio, Sweden, Umea Univ., Sweden: Univ. of Nottingham, UK and The School of Cognitive and Computing Sciences, Univ. of Sussex, UK	Waterworth & Waterworth (2001); Green (2002), Schnadelbach, Koleva, Benford, Pridmore, Medina: Harris, Smith	2001 to 2002	Originally conceived as a multi-signal, multi-modal immersive environment designed to stimulate creativity and non-symbolic communication. Modified to accommodate multiple children at one time, social context	Reflection, meditation, creativity, collaborating, story telling		
36	**Storytelling and Avatar Guides "Geist"**	Interactive Graphics Systems	Department of Computer Science, Technische Universitat Darmstadt, Germany	Braun	2003	Computer Supported Collaborative Storytelling application implemented in an AR framework:	Thirty Years' War, Heidelberg, Germany: interactive history, embedded in non-linear interactive collaborative story at the castle's site		German Federal Ministry of Education and Research (BMBF)

Projects Summary and Results

Simulated Ecological Environments for Education

Table 4: Projects Summary and Results

Educational Tests — *Methods & Results (Quantitative)* — *(Qualitative)* — HCI Tests *(Quantitative)* — *Impact on Learning*

	Name	No. Subjects	Control Group	Pre-test	Post-test	Retention Test	Transfer Test	Subjects Conversations	Subjects Gathered Data	Subjects Concept Map	Subjects Journal	Subjects Art	Web log	Timed Task (min)	Free Choice Navigation	Constrained Navigation	RT	Errors	Significant	Statistical Data
	TOTAL		3	7	8	3	1	11	14	2	11	2	9	6	25	8	2	1	6	
	%		8%	19%	22%	8%	3%	31%	39%	6%	31%	6%	25%	17%	69%	22%	6%	3%	17%	
1	The KidsRoom Project													12		1				Cause and effect important, story & roles important
2	NICE Project										1	1	1		1					
3	NewtonWorld	30		1	1										1				0	No evidence of a statistical significant difference between pre and post test
4	MaxwellWorld	28		1	1	1									1				1	Test comparing 2D and 3D posttest improvement: concepts improved on (2D) by 0.58 % and on (3D) by 0.70 %. And for 3D demos on (2D) 0.67% and on (3D) 0.87%: The Retention test showed improvement 3D demos of (2D) by 0.31% and on (3D) by 0.57%
5	PaulingWorld																			(not reported)
6	Global Change World	56			1					1	1				1				0	Evidence of generalizing local concepts incorrectly to global concepts
7	The Virtual Reality Gorilla Exhibit														1					
8	The Round Earth Project	76		1	1	1	1	1		1					1				1	From pretest of 7.3 correct to posttest of 12.9 and a delayed posttest of 11.4 means, significant at p<0.5
9	The Field: v1: 1999								1					20	1					
10	The Field: v2: 2001							1	1		1				1					
11	The Field: v2a: 2001							1	1		1				1					
12	The Field: v2b: 2001							1	1		1	1			1					
13	The Field: v2c: 2001							1	1		1				1					
14	The Field: v2d:2001							1	1		1		1		1					
15	The Field: v3: 2002 (aka Bee Dance)							1	1		1		1		1					
16	The Field: v4: 2003 (aka My World)								1				1		1					
17	The Field: v5: 2004								1				1	20-	1					
18	Nerve Garden														1					SIGGRAPH 1997
19	Plants and Biological Simulations																			Tool
20	Virtual Kelp Forest	500												3 to 20		1				General Public
21	The Virtual Oceanarium															1				
22	SciCentr and BioLearn														1					
23	Multi-User Virtual Environment	162	1	1	1			1	1		1		1			1			0	No evidence of a statistically significant difference between pre and post test
24	Multi-User Virtual Environment	300	1	1	1			1	1		1		1			1			1	Biological knowledge improved by 32 %- 35%
25	Models and Simulations of Cell for Biology																			
26	Virtual Environment in Biology Teaching	37		1	1										1				1	81% reported that they liked the tool. Biological knowledge improved by: pretest 10 correct to posttest 22 correct AND pretest 11.16 to posttest 28 correct. AND pretest 29 correct
27	Virtual Big Beef Creek														1					
28	The Virtual Field Station	10	1	1	1	1		1	1		1				1				1	No evidence of statistically significant difference between real life field trips and virtual field trip experiences on test scores.
29	MagicBook														1	1				
30	MagicLenses																			
31	eyeMagic Book	10														1				
32	The Ambient Wood	16							1				1	1	1		1			
33	Digital EE	10						1	1				1	1	1		1	1	1	HCI usability and attitude data measured
34	Interactive Art														1					
35	The Tent														1					
36	Storytelling and Avatar Guides "Geist"															1				

Projects Features and Functions

Simulated Ecological Environments for Education

Table 5: Projects Features and Functions

		Technology Used															HCI
			Content	*Model and Simulation*				*No. Users*			*(Output device and Input dev*						
	Name	Computer Graphics	Subject Mater	Data Created Simulation	Artificial Life (Model and Simulation)	Adaptive, Non-Linear Simulation	Ambient	Single	Dyads	Collaborative	Immersive VR	HMD	CAVE / ImmersaDesk / Theater	AR	MR	Desktop	Input Device
	Total			19	16	6	6	17	12	25	19	4	15	9	4	15	
	%			##	##	##	##	##	##	##	##	11%	##	##	11%	##	
1	The KidsRoom Project	Animation, cartoon-style, video	Fantasy adventure - Peter Pan and Wild Things			1	1			1	1		1		1		Computer vision tracking and natural interfaces - no voice recognition
2	NICE Project	Cave and Internet, 3D model, Java and VRML	Garden, but abstract not realistic		1				1	1	1		1			1	Wand in Cave, mouse and keyboard in Desktop
3	NewtonWorld	3D models from NASA	Physics	1				1	1		1	1					Haptic mice, virtual hand
4	MaxwellWorld	3D models from NASA	Electro-magnetic	1				1	1		1	1					Haptic mice, virtual hand
5	PaulingWorld	3D models from NASA	3D model of molecular structure	1													
6	Global Change	topographical contour / 3D models	Seattle area, virtual terrain, some landmarks	1				1	1	1	1	1					Wand and HMD
7	The Virtual Reality Gorilla Exhibit	3D model of the habitat and gorillas	Atlanta Zoo gorilla habitat/exhibit, 3D model of the exhibit and the gorilla avatars	1	1			1			1	1					Buttons and joystick
8	The Round Earth Project	3D model of the earth and the asteroid	Earth and asteroid and mission control, each pare had to find 10 objects						1		1		1			1	Joystick, reduced to only three buttons
9	The Field: v1: 1999	3D model of an abstract field	VE field, flowers (red and white) palm trees		1					1	1		1				ImmersaDesk
10	The Field: v2: 2001	ibid	ibid		1					1	1		1				ibid
11	The Field: v2a:	ibid	ibid		1					1	1		1				ibid
12	The Field: v2b:	ibid	ibid		1					1	1		1				ibid
13	The Field: v2c:	ibid	ibid		1					1	1		1				ibid
14	The Field:	ibid	ibid	1	1					1	1		1				ibid
15	The Field: v3: 2002 (aka Bee	ibid	Addition of two bees	1	1		1	1		1	1		1	1			ibid, added handheld
16	The Field: v4: 2003 (aka My	3D model of an abstract field, handheld visualization map view of individual's Trace and data	No bees	1			1			1	1		1	1		1	ibid, added laptops
17	The Field: v5: 2004	3D model of an abstract field, handheld visualization map view of individual's Trace and data, laptop to visualize combined class data	ibid	1						1	1		1	1		1	GeoWall, handheld, laptops
18	Nerve Garden	L-Systems, VRML, Java, Internet browser	Island, plants, bee, display growth, decay and energy transfer as one would expect in a simple	1	1			1		1						1	PC keyboard and mouse
19	Plants and Biological			1	1												
20	Virtual Kelp Forest	VRML, Internet and video (20 MB)	Accurate model and simulation of the Kelp Forest Exhibit at the Monterey Bay Aquarium (simulated tank hydrodynamics, plants and fish)	1	1			1								1	PC keyboard and mouse
21	The Virtual Oceanarium	Large scale theater, in a facility that can accommodate several hundred visitors. High end computer graphics, AL simulations driven by a supper computer. IDEAL	Lisbon Oceanarium simulation, 1,000 individual creatures and plants. Four ocean habitats. Models consist of plants, fish, seabirds, reptiles and	1	1						1		1				Human guide controls the navigation and the verbal descriptions
22	SciCentr and BioLearn	Active Worlds (activeworlds.com) educational technical platform	SciCentr is a 3D multi-user virtual science museum and BioLearn is a virtual science center based on Davenport beach and it's beach was modeled after					1		1						1	PC keyboard and mouse
23	Multi-User Virtual Environment	Active Worlds (activeworlds.com) educational technical platform and the CMU chemical simulation irYdium Project	River City was based on a historical scenario of a polluted industrial city with environmentally caused illness. The researcher/avatar leads the students on an investigation into a historical fantasy VE, where it is important to collaborate and gather evidence, create hypothesis and test them.			1		1		1						1	PC keyboard and mouse
24	Multi-User Virtual Environment	Active Worlds (activeworlds.com) educational technical platform and the Biology simulation was not	ibid			1		1		1						1	PC keyboard and mouse
25	Models and Simulations of Cell for Biology	VRML?	Cell process and structure	1				1								1	PC keyboard and mouse
26	Virtual Environment in		Cell process and structure	1				1								1	PC keyboard and mouse
27	Virtual Big Beef Creek	VRML and Java 3D	Dynamic process of an estuary ecosystem, based on real data gathered via sensors. 3D geo-spatial data visualized as a VE, avatars that represent eagles,	1	1											1	PC keyboard and mouse
28	The Virtual Field Station	Hyper media, Internet, not VE	Plot study of a beach plot that Mediterranean Sea Turtles use for nesting and the human impact on			1			1	1						1	PC keyboard and mouse
29	MagicBook	ARToolkit	3D models of land, animated Volcano, characters in a book, 3D building and many more	1				1	1	1				1	1		Special mouse and glasses
30	MagicLenses	ARToolkit	3D NASA data set creation of the Earth	1				1	1	1				1	1		Special mouse and glasses
31	eyeMagic Book	ARToolkit	Children's stories		1	1		1	1	1				1	1		Special mouse and glasses
32	The Ambient Wood	Real wood, augmented with WiFi network, FM, RFID wireless speakers and unique output devices	Data found in the woods, such as moisture readings, temperature readings, sounds, video; Back at the lab, PC's used for consolidation of individual data and data visualizations	1			1		1	1				1		1	Handhelds, data automatically gathered on the children's location via GPS and logged in combination with any data that was received or transmitted at that
33	Digital EE	AR networked, internet based, multi-media collaborative component, desktop augmented virtual, video. The Desktop has users avatars augmented with	Kamigamo Experimental Forest - real live video, and the conversations of the field users and the virtual users as they negotiated how to navigate and what							1				1		1	Handhelds and video, automatic GPS tracking: Desktop used mouse and keyboard
34	Interactive Art						1	1	1	1	1		1				
35	The Tent	Projection screen was in the shape of a tent					1	1	1	1	1		1				
36	Storytelling and Avatar Guides "Geist"	AR 3D models of historical characters as the avatars	Thirty Years' War at the Heidelbergh castle, Germany		1	1				1				1			GPS automatic, AR equipped Binoculars

Projects Matrix

Simulated Ecological Environments for Education

Table 6: Projects Features and Functions Detail

		Input Devices					Modalities								Search & Navigation & Context																		
	Name	Mouse & keyboard	Hand held or PDA	Arrow keys	Wand (haptic mouse)	Game control / joystick	Voice	Gesture	Tracking	Multi-modal	Visual	Sound	Haptic	Smell	Frame of Reference	Scale	Ego-centric	Exo-centric	Empath-centric	Story	Problem to solve	Game	Text search	Avatar of Self (virtual hand)	Avatar/Guide (talker)	Empath-Avatar	Map	Index	Tree	Path/Trail	Menus	Tools	Visualizations	Past / Present / Futu
	Total	16	7	16	6	3	12	11	10	14	35	14	3	0	13	16	34	9	5	9	15	4	0	12	13	5	6	0	0	4	17	13	13	9
	%	##	19%	##	17%	8%	##	31%	##	##	97%	##	8%	0%	##	##	94%	25%	14%	25%	##	11%	0%	##	##	14%	17%	0%	0%	11%	47%	##	##	25%
1	The KidsRoom Project						1	1	1	1	1	1	1				1			1		1			1					1				
2	NICE Project	1		1	1		1	1	1	1	1	1				1	1			1				1	1									1
3	NewtonWorld				1		1	1		1	1	1	1		1	1	1							1	1						1		1	
4	MaxwellWorld				1		1	1		1	1	1	1		1	1	1	1						1	1	1					1		1	
5	PaulingWorld																																	
6	Global Change World				1	1		1		1	1						1				1			1	1							1		1
7	The Virtual Reality Gorilla Exhibit					1		1		1	1	1					1		1					1		1								
8	The Round Earth Project	1		1	1	1					1				1	1	1	1		1	1	1		1	1		1					1	1	
9	The Field: v1: 1999										1						1				1										1			
10	The Field: v2: 2001										1						1				1													
11	The Field: v2a: 2001										1						1				1													
12	The Field: v2b: 2001										1						1				1													
13	The Field: v2c: 2001										1						1				1													1
14	The Field: v2d:2001		1								1						1				1										1			1
15	The Field: v3: 2002 (aka Bee Dance)		1								1					1	1		1		1					1					1			1
16	The Field: v4: 2003 (aka My World)	1	1	1							1				1		1	1			1						1				1		1	
17	The Field: v5: 2004	1	1	1							1				1		1	1		1	1						1				1		1	
18	Nerve Garden	1		1							1					1	1							1								1		
19	Plants and Biological Simulations	1		1							1					1	1															1	1	1
20	Virtual Kelp Forest	1		1							1				1		1		1							1					1			
21	The Virtual Oceanarium										1	1			1		1	1	1															
22	SciCentr and BioLearn	1		1						1	1	1					1														1			
23	Multi-User Virtual Environment (2003)	1		1			1			1	1	1			1	1	1			1	1	1		1	1						1	1	1	
24	Multi-User Virtual Environment (2005)	1		1			1			1	1	1			1	1	1			1	1	1		1	1						1	1	1	
25	Models and Simulations of Cell for Biology	1		1							1					1	1																	
26	Virtual Environment in Biology Teaching	1		1							1					1	1				1										1			
27	Virtual Big Beef Creek	1		1							1				1	1	1		1					1		1					1	1		
28	The Virtual Field Station	1		1							1				1	1	1	1			1						1				1	1	1	1
29	MagicBook							1	1		1					1	1			1				1	1							1	1	
30	MagicLenses							1	1		1					1	1	1									1					1	1	
31	eyeMagic Book						1	1	1		1					1	1	1		1					1						1	1	1	
32	The Ambient Wood	1	1	1			1		1	1	1	1			1																1	1	1	
33	Digital EE	1	1	1			1		1	1	1	1			1		1	1						1	1		1			1	1	1		
34	Interactive Art						1	1	1	1	1	1					1																	
35	The Tent				1		1	1	1	1	1	1					1								1					1				1
36	Storytelling and Avatar Guides "Geist"		1				1		1	1	1	1					1			1					1					1				1

Glossary

- **Artificial Life (AL):** A software application or program that computes data consistent with a computational model of some life form, society, community, or aggregate life forms as found in a society. Some of the computational models are static-rule-based; others are dynamic and can exhibit properties of learning. The outputs of the program should be actions and behaviors that mimic the real-life counterpart, at least computationally. The AL application is independent of the user interface.

- **Augmented Reality (AR):** Any 3D computer graphic applications, models, renderings, and animations that are unique to generating and providing visual overlays to the perceived reality for the purpose of augmentation and enhancement of the real visual information. Typically implemented with a type of heads-up output display, such as AR glasses. ARToolkit is an example of software that can be used to create AR applications (Billinghurst et al., 2001). Reality is augmented by AR computer graphic information, and used to extend the perceptual and cognitive functioning of the user.

- **Classroom Virtual Environments (Reality):** Refers to implementation and installation of virtual reality equipment in a classroom for curricular enhancement. May be independent of the hardware or software. It could be immersive, desktop, or any combination of the two.

- **Cognitive Ecology:** The perceptual and the social semantic objects and artifacts that are perceived in the environment or cognized in the mind. That which impacts one’s frames of cognitive reference, perception, thinking, decisions, and actions. Important in that the student may be more or less receptive to learning based on the cognitive ecology of the student’s environment, and thus the cognitive ecology can impact the student’s learning activity.

- **Collaborative Virtual Environments:** Not single- or paired-user virtual environments, but typically virtual environments that are networked to facilitate more than two users interacting simultaneously. User interaction tasks may be work-, problem, or entertainment-based in focus. Many of the new Internet role-playing virtual reality environments are examples of such systems. The users are typically represented as avatars, and the virtual environment persists as users enter and leave. Many have evolved into virtual societies and virtual economies.

- **Desktop Virtual Environments (Virtual Reality):** Independent of the software in the 3D computer model, rendering, or animation applications, the user views it on a typical PC, or the Desktop and a mouse and keyboard, or joystick, or game controller is used for control. Stereoscopic images are not de-facto, yet special equipment can be used to gain the effect. The experience is limited to the small screen, and lacks full sensory immersion that can be found in the other types of virtual reality applications and hardware implementations.

- **Ecological Environment:** All of the entities in the perceptual and cognitive environment combined that are external to the user of the following systems. Real or simulated, it is that which the person, animal, agent perceives, evaluates, learns from, and responds to.

- **Ecology**: Of the world of nature and ***all related energy-efficient life***. Ecosystems in the terms of an ecologist can be viewed as a whole network of energy and material continuously flowing into the community from the surrounding physical environment (Wilson, 2002).

- **Education:** Intentional and often formal actions taken to induce a conceptual change. The act of learning, or changes in the declarative and procedural ontologies that was purposeful and intentioned.

- **Human Computer Interaction (HCI):** A field of study where the usability and the efficiency of computer and software applications, hardware technology, and human factors parameters are designed to approach optimum performance standards set by the users' goals.

- **Immersive Virtual Reality:** The critical distinguishing factor is that the user is perceptually and often physically surrounded by the application's output device. Often, a head-mounted display (HMD) is used to replace reality with the 3D computer graphic models, renderings, and animations. If, physically, the user is inside a CAVE (Cruz-Neira et al., 1993) or a CaveUT, (Jacobson & Lewis, 2005) or a large public theater. Many of these systems have been extended to provide more information to the user through multi-modal perceptual channels, including sound, smell, touch, and even taste. Many different configurations for data input have been used, including computer vision tracking of the user, data glove for gesture input, wands, mice, and voice.

- **Input Devices:** Any hardware component of the user interface that is used to capture the users' signals, the most common of which is the keyboard and mouse. However, it may be a game controller, a joystick, a wand, a data glove, or a microphone.

- **Intelligent Tutors:** Within the field of educational software, this refers to the underlying applications that can guide, usually dynamically, a student through a body of knowledge, either declarative or procedural or some combination of both, with dynamic feedback and navigation.

- **Mix Reality:** Is AR but with the addition of real-world props. Some objects that are perceived are part of the real environment, and some are the 3D computer graphics, models, renderings, and animations. Mixed Reality uses a combination of real-world props and virtual environments (Hughes et al., 2001).

- **Mobile:** Used in the context of a mobile device and that which requires wireless networks for either indoor or outdoor environments.

- **Output Devices:** The device that displays the images that the computer generates. The VE and / or the user interface can be displayed to the user. The most common output device is a PC desktop computer monitor, but many VE applications use CAVEs.

- **Simulated Ecological Environments for Education:** A VE that is highly realistic in image, spatial layout, function, and purpose. It is modeled after a real environment, such as one of nature, and it is based on reality. Based-on-reality is a key requirement, since the designer has the power to create a fictitious model. The danger of a fictitious world is that it will introduce misconceptions into the child's mental model. The point is that the model must be true to life, yet the model may be augmented to facilitate cognition with meaningful abstractions. The second part is that it is a simulation in the sense that the model should accurately represent the interrelationships and dynamic ecology that underlie the relationships. Lastly, like an ideal relationship between an expert guide and a child, the user interface should augment the model in ways that support knowledge gain and procedural strategies, gracefully moving the child from novice to expert in both domain and procedural knowledge at the child's pace, level, and interest-way-finding preferences, and without guide domination.

- **Simulations:** Computer applications that are constructed to model, usually, the dynamic interconnected relationships of many causal variables, but not necessarily in real time or interactively, though they may be. They are used to run different independent variables through the model to compute the dependent variables and the situational outcome.

- **Situated Learning Theory:** An educational theory that argues that learning as it normally occurs is a function of the activity, context, and culture in which it occurs, or is situated. Not classroom-based, it is usually unintentional rather than intentional. It is a general theory of knowledge acquisition where the knowledge must be presented in an authentic context (Lave & Wenger, 1990; McLellan, 1995).

- **Ubiquitous Computing:** An environment that is saturated with computing communications abilities, so that the computer become invisible and the user is not burdened with devices, learning curves, attention-demanding special computer commands. An environment where the human can be a human and behave naturally, and yet have access to the computing environment to facilitate daily activity, problem-solving, information needs, planning, and optimization activity in any location at any time (Weiser, 1991).

- **Virtual Environment (VE):** Is the software and computer technology required to create virtual reality. Real time, interactive 3D computer graphics, models, renderings, and animations that are supported by a real-time, interactive user interface, model, applications and computer hardware. Most models are typically constructed to resemble the entities found in reality, with high visual fidelity, sometimes stereoscopic, sometimes with spatialized sound. Some content is identical to reality, built from real data; others are close to reality, but built with real-time interactive constraints in mind; yet others are fantasy constructs that may or may not resemble entities on earth or in reality. Some of these models persist, and others do not. Some are static, and others are dynamic over time. Some are for only one user; others allow entire societies to interact. Often, VE is used as a term independent of the hardware, so it can be used to describe both a CAVE-based implementation and a desktop implementation.

- **Virtual Reality (VR):** Much literature has discussed the requirements of "autonomy, interaction and presence" as resulting cognitive states of such interactions for VR (Zeltzer, 1992). VR is a state of mind independent from the technology used to create it. It is not reality; it is a computer-constructed version of reality that is experienced as reality.

- **Visualization:** A graphical representation of data that is useful in the processing of the data into a mental model of the reality, for the purpose of revealing otherwise obscure relationships (Spence, 2001).

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