

# Exploring Multiple Representations In Elementary School Science Education

Andrew Johnson, Thomas Moher, Stellan Ohlsson, Jason Leigh  
University of Illinois at Chicago, Chicago, IL, 60607, USA  
(312) 996-3002 voice, (312) 413-7585 fax  
ajohnson | moher | stellan | spiff@uic.edu

## Abstract

*This paper presents our findings after the first year and a half of a multi-year deployment of an ImmersaDesk® to a local elementary school, investigating its effectiveness in enhancing science education. These findings deal with how VR can aid in the coordination of multiple representations, and how to integrate the technology into the existing school culture.*

## 1. Introduction

In August 1999 we moved an ImmersaDesk into Abraham Lincoln Elementary School in Oak Park, Illinois as part of a multi-year study into the use of VR in elementary school science education. So far over 250 students have used the ImmersaDesk at the school to interact with a series of conceptual learning environments designed to study the effectiveness of VR-based learning strategies for coordinating multiple external and internal (mental) models of scientific phenomena. These studies focus both on supporting individual learning, and providing it effectively within the constraints imposed by the classrooms of contemporary schools.

The objective of our effort is to maximize the effective use of this technology in a single working public elementary school by providing a rich resource and support base, and a broad range of participation opportunities. A central theme running through our integration efforts is the alignment of all of our activities with the school's learning goals, curriculum, and operating practices so the teachers feel confident that participation is not adding irrelevant activities to an already crowded curriculum. While our long-term goal is to impact these criteria, we can not impose a decontextualized solution, but rather we must discover together an evolutionary path to the future.

Our long-term goal is to help prepare the nation's schools for the advanced visualization technologies such as VR that are becoming operative in research laboratories. The ability of children to successfully adapt to today's clumsy controls and low-resolution displays, and their accelerated learning capacity provide at least prima facie justification for exploring these new media. Recent empirical studies [3, 8, 14, 17] provide initial evidence of learning gains using VR-based environments with students ranging from second grade through high school.

Whether this technology will be adopted depends on whether we can find more solid evidence of effectiveness for the individual learner, and whether we can successfully align its use with school goals, curricula, practices, and culture

While the history of meaningful technology adoptions in schools has been discouraging [4], we have the advantage of the lessons learned from the computing integration efforts over the past two decades. The central theme of that experience has been the recognition of the importance of addressing the needs of the individual learner while respecting the constraints imposed by the educational context within which learning occurs. Therefore we are seeking answers to the following research questions:

1. How does VR interact with the cognitive processes involved in learning, and can we exploit this knowledge for the development of effective educational interventions?
2. How should VR be incorporated in the classroom, into current teaching practices, and into the life of the school?

Section 2 discusses our use of this technology in constructing and coordinating mental models. Section 3 describes the VR resource in the school, and section 4 describes the three tracks of research that we are pursuing using that resource. Section 5 gives some of our current findings and section 6 looks at our current directions in our second year at the school.

## 2. Multiple Representations

We are focusing on the role of coordinating multiple representations as the central process in science learning. The adage that 'a picture is worth a thousand words' has intuitive appeal, but cognitive scientists do not yet understand under what circumstances multiple representations have positive consequences for learning.

Learning fundamental ideas in science requires that the learner construct mental models of the system to be understood – integrated dynamic representations that support argumentation, explanation and prediction. Visualizations facilitate this construction. However construction is not enough. Learning fundamental ideas in science re-

quires that the learner coordinate multiple mental models. There are several kinds of mappings that can be used to accomplish this.

## 2.1 Constructing a Mental Model

Knowing a fundamental idea in science is not merely being able to repeat its standard verbal formulation, or to solve a canonical set of textbook problems. Verbal formulations and problem-solving skills can be acquired without understanding. Instead, cognitive and educational researchers have converged on the hypothesis that understanding an idea requires that the learner construct an internal representation, often referred to as a mental model, of the type of system for which that idea is relevant. A mental model is an integrated, dynamic representation that allows the learner to simulate the relevant system in the mind's eye. Mental models support argumentation, especially counterfactual reasoning, explanation and prediction.

Educational materials abound with visualizations. Visual representations support mental models in numerous ways and the more powerful the visualization technology, the more complete the support:

- Integration. Visual representations provide simultaneous and parallel access to multiple parts or components of the visualized system, while a text necessarily presents them in some sequence, leaving the learner with the task of integration.
- Dynamics. Dynamic visualizations demonstrate how components of a system interact and change over time.
- Reification. Visualizations can convert abstractions into perceivable objects and engage perception in support of conceptual learning.
- Activity. Interactive visualizations allow a learner to manipulate a system, and draw upon the near-universal principle that knowledge is constructed in the course of activity.
- Immersion. High-end visualizations combine all of these features to let the learner feel as if he or she is directly experiencing the visualized system, thus drawing upon children's natural capacity for experiential learning.

However, recognizing the power of advanced visualizations to support the construction of mental models does not specify which visualizations are most useful for particular topics. Additional principles are needed.

## 2.2 Coordination of Multiple Models

If the coordination of multiple representations is central to science learning, then pedagogical visualizations should be designed to support these different types of mappings. In VR a common mapping is one between exocentered and endocentered representations [5]. This is

a relation between two different perspectives, in the literal sense of views from different positions in space. However, there are many different types of mapping relations, and different mappings are relevant for different learning targets. For example:

- Time. the successive stages in mountain formation, or time slices of an eroding shoreline.
- Transformation. a process running at different speeds, or an object undergoing changes in shape.
- Scale. the mapping between the normal and the molecular view of a substance or between a tissue and its components cells.
- Part-whole. the mapping from the components of an electrical circuit to the behavior of the circuit as whole, or from orbit, rotation and the tilt of the Earth's axis to the march of the seasons.
- Form-function. the relation between the shape of a DNA molecule and the process of duplicating the genetic code.
- Abstraction. the relation between a photo of a baseball homerun and the corresponding force diagram for projectile motion.
- Interpretation. the relation between hypothesis and evidence, or between alternative hypotheses.

Each type of mapping is involved in learning some scientific concepts; each presents the learner with a challenge. However, noticing that particular subject matter topics include certain mappings does not exhaust the importance of coordinating multiple representations and models. Cognitive research has also provided empirical support for at least two types of mappings that have greater generality: analogy and schema articulation.

According to the analogical transfer hypothesis, the learner can construct a new mental model by mapping a novel system onto an already familiar one. For example, by mapping conduits onto wires, water sources onto batteries, and so on, a learner can construct an initial (partial) mental model of how electricity works. Unlike the mappings considered above, analogical mapping is not tied to any particular subject matter. The main limitation is the availability of a useful analogue.

According to the schema articulation hypothesis, a mental model can be constructed by filling in an abstract schema in a novel way [12, 18]. For example, the Darwinian schema of change in a population via variation and selection can be articulated to explain why bacterial diseases become resistant to antibiotics and how the immune system works. Like analogy, schema articulation is not intrinsically tied to particular subject matters. The main limitation is the availability of a suitable schema.

The issue of multiple representations is not straightforward. Several researchers have suggested that the presentation of multiple representations is beneficial in and of itself, without any additional support. Multiple representations have been hypothesized to help because they provide redundancy at different levels of abstraction [6], pre-

sent complementary aspects of the subject matter [2], influence the allocation of attention [16], induce distinct cognitive processes [10], or provide a better fit to individual learning styles. Salzman, et al. [17] recently provided support for this idea in a conceptual learning task involving electric fields. In their study, high school students who interacted with both an exocentered view and an endocentered view of an electrical field exhibited a significantly higher level of mastery than students who interacted with only one of these visualizations.

However there are strong reasons to believe that the issue is more complicated than "two representations are better than one." Constructing a mapping between multiple mental models is itself a cognitive task at which the learner can succeed or fail. This is illustrated by Ainsworth, et. al. [2], who found that two visual representations in combination produced a significantly lower learning outcome than either representation by itself. Presumably, the students in this study could not compute the relevant mapping, or else allocated so much working memory to creating the mapping that it interfered with other aspects of their learning [19].

Consistent with this outcome, research on analogical reasoning has demonstrated that neither children nor adults are strong mappers. Children in particular have a tendency to relate representations to each other on the basis of surface features, rather than the deeper features that would be more helpful. Teachers, tutors, and transitions between the various representations are needed to coordinate the representations.

### 3. The VR Resource in The School

In 1997, we conducted VR-based learning studies with over 80 elementary school children within the Electronic Visualization Laboratory at the University of Illinois at Chicago. It became obvious that a much better solution would be to conduct these studies within an elementary school itself. In December 1988 we moved an ImmersaDesk into a classroom at Abraham Lincoln Elementary School in Oak Park, Illinois for a month-long research project with 76 2nd graders looking at these issues of multiple representations in terms of the shape of the Earth [8]. In August 1999 we returned to Lincoln on a more permanent basis.

Abraham Lincoln Elementary School is a K-6 elementary school in Oak Park, Illinois, a racially and economically diverse inner-ring suburb bordering Chicago's West Side. Lincoln is attractive as a research site for its size, diversity, and state of technology adoption. It is a large school (620+ students), nearly always allocating four (20-30-student) classrooms at each of the K-6 grade levels. Besides a racially and economically diverse student body (64% white, 29% african american, 4% hispanic, 3% asian) and faculty, Lincoln offers diversity of subject mastery, as reflected by IGAP (Illinois Goal Assessment

Program) and Stanford-9 achievement tests administered at the school. While performing moderately above average as a school, Lincoln has significant representation in all performance quartiles. The school is also roughly average with respect to technology infusion, with about one computer for every five children, distributed both in classrooms and in the school's Media Center, and an orientation more toward computer literacy and technology education than conceptual learning.

We have the advantage of a strong pre-existing relationship with Lincoln. One of the members of our team was an active Lincoln parent for twelve years and a member of the Board of Education. We bolstered that relationship through a series of meetings both at our laboratories, familiarizing teachers with our VR technology, and at the school, familiarizing researchers with the realities of a contemporary elementary school.

The current equipment at Lincoln consists of an ImmersaDesk driven by a 4-processor SGI deskside Onyx IR, and a 19" stereo monitor driven by a dual processor SGI Octane. While most of the work takes place at the ImmersaDesk, the Octane allows us to explore collaborative virtual environments, specifically those with heterogeneous views of a shared space. We run both screens at 1024 x 768 in 96Hz stereo. Both computers are wired to send audio to the ImmersaDesk's speakers. When we are conducting more formal learning studies we bring in recording equipment such as cameras and microphones.

The equipment is located in a room next to the school's Media Center. This location was determined in consultation with Lincoln administration and staff, and is designed to minimize the impact of 'pull-outs' from regular classroom activity. Since classes regularly visit the school's Media Center, its possible to 'pull over' students to work individually or in small groups while the rest of their class is doing other activities in the Media Center. Since the Media Center has its own instructor, a teacher can accompany his or her students in the activity at the ImmersaDesk while the media center teacher works with the rest of the class. The Media Center also contains a cluster of 26 networked iMacs, allowing us to investigate collaborative activities between children who are immersed and children at desktop computers.

### 4. Three Tracks of Research

We are currently performing three tracks of research at Lincoln. All three focus on multiple representations, but in different ways. The Cognitive Studies are in-depth studies of learning that focus on the coordination of multiple perspectives in the formation of mental models. The QuickWorlds focus on augmenting the existing classroom visualizations (textbooks, filmstrips, 3D models) to give the students an additional, more interactive, visualization of the material. The Virtual Ambients help students understand the scientific method by following data through

the process from collection through abstraction. These three tracks of research also support different types of VR experiences. The Cognitive Studies focus on individual learners, the QuickWorlds focus on small groups, and the Virtual Ambients focus on whole classrooms.

#### 4.1 Cognitive Studies

The Cognitive Studies track [8, 13] involves conducting in-depth learning studies with an entire grade level of individual learners. These types of studies take several weeks to complete the pre-testing, VR experience, and post-testing. It requires a high level of commitment both from the teachers and the researchers as it involves pulling out each student from class three to four times. During the time the children are pulled out of class, they are interacting with the VR technology and the researchers, but not their usual classroom teacher. This creates good conditions for a formal study but is not very realistic in terms of common school usage.

Our first study in 1998 at Lincoln, with the second grade, showed a very significant improvement in the children who went through the VR experience of walking on a small-diameter asteroid and the subsequent dialogue relating the experience to the Earth. Our second study at Lincoln, with the first grade, compared students who experienced the VR asteroid and took part in the dialogue to those who only had the dialogue. Both groups of students showed significant improvement, and we are still analyzing the differences in the various knowledge components.

Working with the 1st graders brought up developmental issues which were not obvious with the 2nd graders. Quite a few of the 1st graders had difficulty giving directions to their partner who they saw as an avatar. They had trouble taking their partner's viewpoint. Because of this we are augmenting our Round Earth work with another world. 'Piaget World' draws upon the classical demonstration by Jean Piaget of what he called 'egocentrism', but instead of demonstrating the inability to imagine a different point of view than one's own, we will use a VR version of Piaget's set up to help young learners overcome it [15].

The Piaget World visualization consists of an exocentered view of an alpine landscape with various objects (cottage, river, etc), replicating Piaget's pasteboard model. Depending on the viewer's point of view, different objects are occluded by features of the landscape. Four heads provide multiple possible viewpoints, and the child has the ability to 'become' a particular head, changing their visual perspective, to verify what that eyeball can see. We are currently pilot testing this world.

#### 4.2 QuickWorlds

The QuickWorlds track is intended to provide a fast-turnaround mechanism for teachers who would like to make virtual dynamic models available to their students

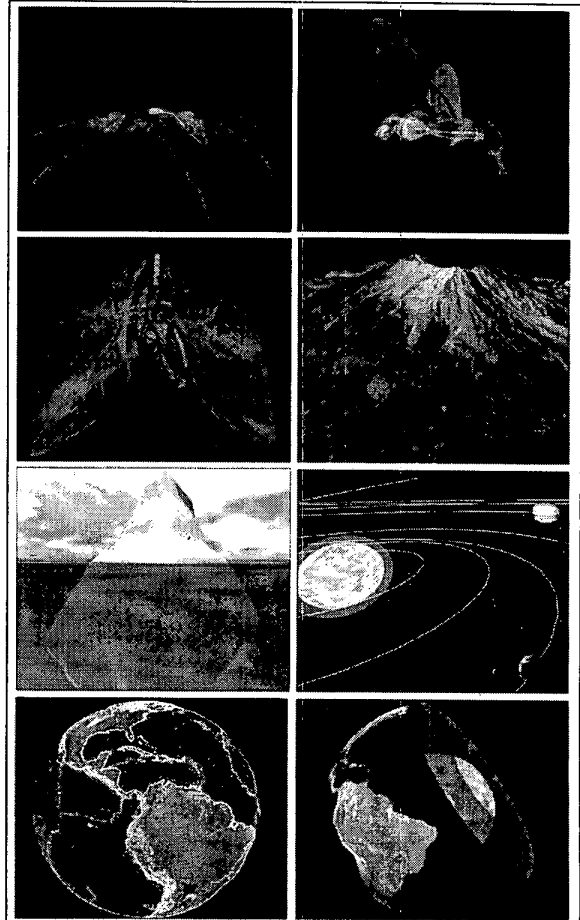


Figure 1: A selection of QuickWorlds that were developed in our first year and a half at Lincoln: a wood ant and bee with internal organs, a beating human heart with lungs showing blood flow, Mt. St. Helens before and after the eruption, an iceberg, the solar system in scale to show the vast distances involved and out of scale to show the details of the planets, the distribution of earthquakes over the Earth, and the interior of the Earth

as part of the regular learning program. VR provides a mechanism for making additional models accessible to students without the costs of physical fabrication. VR also makes models accessible that would not otherwise 'fit' inside a regular classroom.

This track involves a teacher bringing several of his or her students to the ImmersaDesk for 15 to 20 minutes to view an interactive 3D model as part of an existing curricular unit. Depending on the number of children per group, five to eight sessions may be needed for all of the children in a class to participate. The teacher controls the virtual experience and the researchers remain in the background as much as possible.

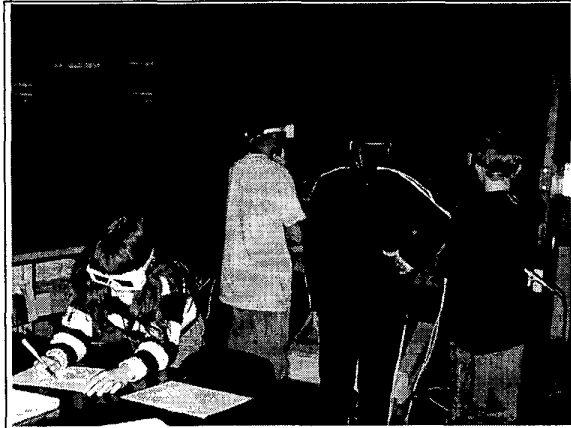


Figure 2: Photograph of four 6th graders exploring one of the virtual ambient environments to collect data. The children rotate through the roles of navigator, spotters, and note taker. Afterwards, they will then return to their classroom and integrate their data with the data of other groups

The teachers request these models and tell us what features we should emphasize. We then build the virtual models and make them available at the school. Several of the QuickWorlds that we have made on request from the teachers are shown in Figure 1. We wanted this track to require a minimal commitment from the teacher. It focuses on the ImmersaDesk as just another presentation medium for the teachers to use, and we are interested in observing how they use it.

For example, the physical education teacher requested a model of the human heart for her 4th graders. She currently teaches about the heart using ‘heart land’ where the children roll around on the gym floor moving dodgeballs from place to place. She wanted to augment this with a more realistic animated model showing the blood flow through the various chambers. This allowed her to help the children relate their participatory model of the heart on the gym floor to the actual shape and function of the heart. She used the VR experience to ask questions of the children and prompt a dialogue.

Initially the teacher would talk to the students while we would manipulate the model, but the teacher quickly took over and began manipulating the model herself, eventually giving control over to the students. All of the QuickWorlds have a dynamic cutting plane allowing the teacher or students to dynamically slice through the model and see the internal structure – this became a very popular feature in helping to focus attention on key parts of the model. Head tracking the teacher was helpful because it made it easier for her to set up appropriate views so the students could see exactly what she was talking about. The large screen was useful in allowing the groups of children to all see what was happening while they were talking about it.

### 4.3 Virtual Ambients

The Virtual Ambient Environments track [11] uses VR as a small part of a larger full-classroom unit where the students survey a large virtual space and then integrate their data as a class. The nature of inquiry (methodology, or the philosophy of science) is seldom taught as a subject matter in its own right. Benchmarks [1] claim that it should be, and the district’s science curriculum identifies it as a central learning goal. Data collection has long been believed to be a valuable component of activity-based learning strategies, but for practical reasons is often replaced by pre-constructed databases. VR appears attractive for this purpose because it can provide access to simulated environments which might otherwise be impossible to visit in person, while still providing experiences analogous to those undertaken by a scientist in real experimental work.

We also believe that the act of collecting and transcribing data will promote conceptual understanding by making the connection between the environment being studied and the ‘scientific’ representations of data drawn from that environment explicit. Evidence from other domains gives credence to this theory; Holst [7] for example, found that degrading the user interface to algebra-learning software – requiring the students to do manual data within a fixed time period - resulted in both fewer interactions and a significantly higher level of content mastery. Such evidence highlights the need to balance between scaffolding on the one hand, and engaging in low-level activities associated with scientific investigation on the other.

In our first year at Lincoln two classrooms of 6th graders and one classroom on 2nd graders visited the same virtual space. The current space is a large flat field, the size of several football fields, laid out in the form of a tic-tac-toe board. Eight different kinds of plants are scattered throughout this space in clusters.

In the first phase of the experience a ‘scouting team’ of 3 or 4 children spend about 30 minutes wandering around the space on their own. They take notes on what they see in the virtual world and then present their findings to the entire class. The entire class spends an hour taking about how to systematically survey the space, then the class breaks into groups of three to four students, and each of those six groups spends 20 minutes in VR. Each of these groups surveys their piece of the virtual world taking notes on what they find. See Figure 2. For the second graders their task was to find how many different plants there are in the space and to draw each of them. For the sixth graders their task was to find correlations between which types of plants grew together. After the VR experience, two more hours of class time were used to integrate the data, and in the case of the sixth graders to convert their collected data into symbolic representations and discover the ‘rules’ of the space.

So far in our second year at Lincoln we have had one classroom of 4th graders survey the space. This time instead of dividing up the class to collect data from different areas of the field, the different groups of children visited the field at different times to investigate the relative growth rates of the plants; the growth rate of the plants over six months was simulated over two days.

These experiences combine work with the classroom teacher and the researchers, and try to more directly investigate how to use VR as part of a classroom activity. As with the QuickWorlds, the large screen was valuable in allowing the groups of children to see the space and talk about its features at the same time. The children typically divided the labour into rotating jobs such as the navigator, and the note-taker, and one or two spotters on the look out for plants in the space.

## 5. Lessons Learned

At the end of our first year and a half at Lincoln, over 250 children have had a learning experience incorporating the ImmersaDesk. Almost all of the 2nd and 4th graders, half of the former 6th graders, and one quarter of the 2nd, 3rd and current 6th graders have participated. We have learned lessons in terms of the use of the technology, the logistics involved in making this technology available, and how to evaluate the learning that goes on.

### 5.1 Technology

Many of the children are familiar with using videogame controllers. As such they had an easy time using the buttons on the Wanda™ we are using as our main interaction device, but had a harder time with the isometric joystick. They also tended to treat the Wanda as a two-handed controller, like a videogame controller, rather than a one-handed tracked pointing device. Typically we have used the joystick on the Wanda for movement and the buttons for actions within the environment. Since the Wanda has only three buttons, its not easy to map movement onto the buttons. Because of this we have been investigating more conventional video game controllers with four buttons in a diamond for movement as well as additional buttons for additional functions. Ideally we'd like to transition to specific physical input devices targeted to the particular applications.

By remaining in the school over several years we are able to investigate repeated usage of the technology. Almost all of the 4th graders taking part in the virtual ambient work this year participated in our Round Earth work two years ago. These children were familiar with the technology from their earlier experience and easily transitioned to the new application.

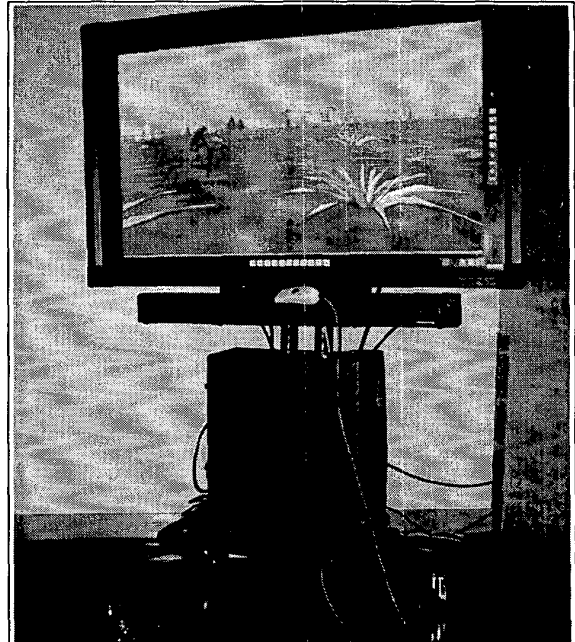


Figure 3: Photograph of the prototype plasma panel and SGI Linux machine running one of the Virtual Ambients that we will place in a Lincoln classroom.

Even with the children's experience with videogames, most of them found the ImmersaDesk and its virtual worlds to be quite impressive: 'Sweet!' being the most common comment. Several students also favourably compared the experience to their Sony Playstation®, but of course they wanted to know if we had more games. While this does motivate the children, it is exactly this novelty effect that we are trying to get beyond through this long-term deployment to the school.

We have tried to keep the frame rates high (at least 15 frames per second), avoided high-vection imagery, and focussed on large open spaces in the worlds. Even so, we have had one serious case of simulator sickness out of the 250 children that have experienced the ImmersaDesk in the school. This child was in a group of four children exploring one of the Virtual Ambients and was not being tracked when she became ill. We found out later that this child was susceptible to carsickness and had trouble at OmniMax films. Interestingly enough this incident did not dissuade any of her classmates from taking their turn. We also had one other student who was interacting alone with the ImmersaDesk as part of the cognitive studies. She had no trouble using the non-tracked glasses at the stereo monitor, but decided to stop as soon as she put on the tracked glasses at the ImmersaDesk. In both cases it seemed like the large amount of sudden movement covering their visual field (either from the non-tracked child

seeing the world move dramatically when the tracked child moved his head quickly, or from putting the tracked glasses on) overwhelmed them.

Because of these incidents we have adopted the following strategy for head-tracking:

- If we have one child in front of the ImmersaDesk, then that child is head-tracked.
- If we have a teacher leading a group of children at the ImmersaDesk then the teacher is head-tracked to give the children the most appropriate view. The teacher knows not to make sudden head movements.
- If we have several children in front of the ImmersaDesk then we turn head-tracking off since this avoids the intrusion of regularly exchanging the head-tracked glasses, and keeps the image stable.

We have noticed several times, children who are not head-tracked acting like they are tracked, trying to look around virtual objects; there is clearly an interest in being tracked. Our goal is balancing that interest with safety.

More details on what we have learned about working with the technology in the school can be found in [9].

## 5.2 Logistics

The children not only enjoyed the VR experience, but also the pre-testing and the post-testing. We believe this is partly because they are out of class, but also because it gave them a chance to interact with an adult one on one.

While we initially hoped to pull students over from the Media Center, we have mostly relied on pull-outs from class since the students' time in the Media Center is generally limited, and very focused. While we can rely on pull-outs for a research program like this one, that path will not be a sustainable model in the school.

Because of this there are a couple different routes that we are going to explore in terms of how to integrate the technology into the school. The first path involves a scenario where high end, rare, technology is deployed in a single space in the school. This is basically the setup that we have now. Thus the 'VR room' would be similar to the music room or the art room in the school where equipment is staffed by an expert who can support all of the students in the school on a scheduled pattern.

An alternative strategy is to rely on more consumer level technology and move the device into the classrooms. The virtual worlds that we have been using at Lincoln are based on SGI Performer, and Performer runs on both SGI machines and on Linux machines. We have ported all of these worlds to Linux and have run them on a Linux based ImmersaDesk. The stereo support on graphics cards under Linux is still weak, however the worlds do run at roughly Octane level speeds in monoscopic mode.

In the spring of 2001 we will deploy a 50-inch plasma panel, running some of these worlds, driven by a Linux machine, to the 4th grade open space at Lincoln where the four 4th grade classrooms share a common large room.

The panel will not be head-tracked, for the same reasons we have not been head-tracking the ImmersaDesk when multiple students are interacting, and will not show stereo visuals. The panel will include hand-tracking, and a wand for navigation and interaction, as a tracked hand is useful for pointing at objects in the virtual ambient field, and in manipulating the cutting plane in the QuickWorlds. We may also add a touch-screen to the panel. This setup reduces the cost of the hardware by a factor of 10 from roughly \$250,000 to roughly \$25,000. See figure 3.

We are trying to leverage the children's willingness to spend hours with a couple friends in front of their TV with its game console, but providing more meaningful content. This will give the teachers more of a chance to use the world opportunistically; the screen will always be left on giving a 'fifth wall' to the classroom. For example this fifth wall could be constantly showing one of the virtual ambient environments allowing the children to easily visit it and explore regularly, just as they might regularly visit a field next to the school.

Our goal at this point in the research is to move beyond being an interesting novelty and towards being an integral part of the curriculum. Teachers are busy people, and we need to prove to them that the time they spend working with us is really valuable to their students. But its not simply a matter of increasing the number of curricular units that we can augment with VR, but also offering a capability that is useful in the long-term.

## 5.3 Evaluation

Probably the most important lesson we have learned is that we have not found the 'silver bullet' for assessing the effectiveness of these interventions. Assessment of learning has defied consensus in the education community, so this should not be a surprise. Simple comparisons between this new way and the 'standard' way of teaching the material are not very meaningful since there are so many factors that could contribute to the success or failure of the new intervention

In the Cognitive Studies we are employing pre-tests and post-tests with questions are asked verbally, through pencil and paper drawings, and through 3D models looking for statistically significant improvements in the different treatments, and looking more in depth at individual learners. In the QuickWorlds the evaluations are more anecdotal at this stage, based on the impressions of the classroom teacher. For the Virtual Ambients the evaluation will be longer term, looking for improvements in the students methodology, not just the end product.

## 6. Current Directions in Year Two

The first year and a half of this deployment have shown us that there are a great many issues related to the coordination of multiple perspectives that we will pursue more

in the coming years. The lessons learned from the previous year suggest that the hardware is robust enough to deploy in a school, but being in the school is not enough. We need to be in the classroom. In either case we need to continue working on our tools for learning assessment.

We are currently running a pilot study with the Piaget World that will lead into the third large cognitive study with the Round Earth next spring. We are building more QuickWorlds, though this term we may focus their use on smaller groups of children who need extra help with a topic. We are continuing with the Virtual Ambient work involving 4th graders and the 6th graders looking at issues of sampling. In the spring the 6th graders will return to the same space three times, each time with an increasingly complicated space to sample. We will continue to have the Deskside Onyx and the Octane in the Media Center with the ImmersaDesk, and will deploy the plasma panel driven by a Linux machine to the 4th grade Open Space.

We are also beginning an NSF funded collaboration with the University of Michigan, Northwestern University, and Georgia Tech to combine their PC-based science inquiry tools with our VR work to create more comprehensive immersive inquiry environments.

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