Editors: Michael Macedonia and
Lawrence Rosenblum

Augmenting Elementary School Education with VR

Andrew Johnson, Thomas Moher, Yong-Joo Cho, Ya Ju Lin, Dave Haas, and Janet Kim

University of Illinois at Chicago

Teachers have always relied on local environments to give students something to observe and measure—collecting leaves in a field, measuring a stream's acidity, or surveying the height of a hill. Local environments have the advantages of being accessible and real. However, they also have three important drawbacks: they might emphasize activity over learning, limit the domain of inquiry, and constrain teachers' ability to scaffold learning by reducing complexity.

We believe that using a virtual world to teach scientific investigation can be beneficial in preparing elementary school students for doing these sorts of investigations in the real world. The students can explore environments that aren't locally accessible and measure phenomena they wouldn't normally be able to. More importantly, a teacher can simplify the complexity of the world to focus on particular features.

At the University of Illinois at Chicago's Electronic Visualization Laboratory, we use virtual reality technology to complement real-world experiences rather than replace them. For more than two years, we've been deploying ImmersaDesk applications in a Chicago-area elementary school. We want to know whether these virtual environments (VEs) help children make sense of mathematics and scientific phenomena. If so, can educators adapt them to the realities of elementary school learning and teaching? Our experience indicates that VR can successfully augment scientific education as well as help to equalize the learning environment by engaging students of all levels.

Learning science inquiry skills

What should young learners know? According to the American Association for the Advancement of Science (AAAS), children in Kindergarten through the second grade (K–2) should be actively involved in exploring phenomena. There should be lots of time to talk about what they observe and to compare their observations with others'. An important part is telling others what they see and what they think, so a premium should be placed on careful expression. Teachers and parents shouldn't expect students at this level to come up with scientifically accurate explanations for their observations. Theory can wait.

According to the AAAS, children in grades 3–5 should gain experience in conducting simple investigations of their own and working in small groups. They should observe more and more carefully, measure things with increasing accuracy, record data clearly in logs and journals, and communicate their results. Class discussions of the procedures and findings can provide the beginnings of scientific argument and debate. However, research studies suggest that there are some limits on what to expect at this level of intellectual development. The design of carefully controlled experiments is still beyond most students in the middle grades.

Abraham Lincoln Elementary School

Our partner in this work is Abraham Lincoln Elementary School, a K–6 school in Oak Park, Illinois, an inner-ring suburb bordering Chicago's West Side. It's a large school with more than 620 students, nearly always allocating four (20–30 student) classrooms at each grade level. Besides a racially and economically diverse student body (64 percent white, 29 percent African American, 4 percent Hispanic, and 3 percent Asian) and faculty, Lincoln offers diversity of subject mastery, as reflected by Illinois Goal Assessment Program (IGAP) and Stanford-9 achievement tests administered at the school.

We've been working with Lincoln Elementary since December 1998 when we moved an ImmersaDesk there as part of our ongoing work in using VR to help teach young children about the Earth's shape. Since then, more than 425 students have used the ImmersaDesk at Lincoln with various educational environments. This experience at Lincoln has taught us that just being in the school isn't enough—we need to be in the classroom as well.

In spring 2001, we augmented the ImmersaDesk with a mobile cart consisting of a 50-inch plasma panel driven by a Linux PC, with an additional PC to handle tracking from a PC bird. We lose stereo visuals and typically don't do head tracking with the plasma panel, but we retain hand tracking, audio, and the ability to support small group work while running the same applications as on the ImmersaDesk.

Big displays for small groups

Much of the activity in elementary schools is organized around small groups of children rather than individual work. Similarly, when children play with game consoles at home, it tends to be a small group of children with shared control around a relatively large display. On the other hand, it's difficult to have a group of students gather around a computer monitor in the classroom because the screen is too small. An ImmersaDesk's 6-foot by 4-foot screen is big enough for three to four students to stand in front of, but it doesn't fit easily inside a working classroom. A 50-inch plasma panel is big enough for two to three students and does fit easily inside a classroom. These big displays encourage the students to interact with each other while interacting with the VE on the screen.

1 **Four sixth graders explore the Field at the ImmersaDesk.**

We stress observation in these scientific inquiry worlds over interaction. The children are there primarily to observe phenomena and not to affect them, so their primary control is navigation. We imposed this constraint to reduce the cognitive burden of exploring the space. It also makes it much easier for the students to walk up and start exploring the world without much instruction. The students can still articulate and investigate an hypothesis, but as in astronomy, they can't manipulate the variables of their study.

Over the past two years we have been regularly using two scientific-inquiry worlds at Lincoln Elementary: the Field and the Bee Dance.

The Field

The Field is a square patch of flat ground, 3,000 feet on a side divided by picket fences into a 3×3 grid. This field contains trees, rocks, and plants. We designed the field to be big enough that students can't stand in the center and see all the important details but small enough that they can survey the space within a reasonable amount of time. The students can move around on the surface, plant flags at points of interest, and take "snapshots" of the space. Classrooms are usually divided into groups of two to four students each to visit the Field (see Figure 1). Typically, each group will explore one of the nine sectors. We have also broken up the Field temporally so each group can visit the Field in a different virtual month to see the plants' growth rate.

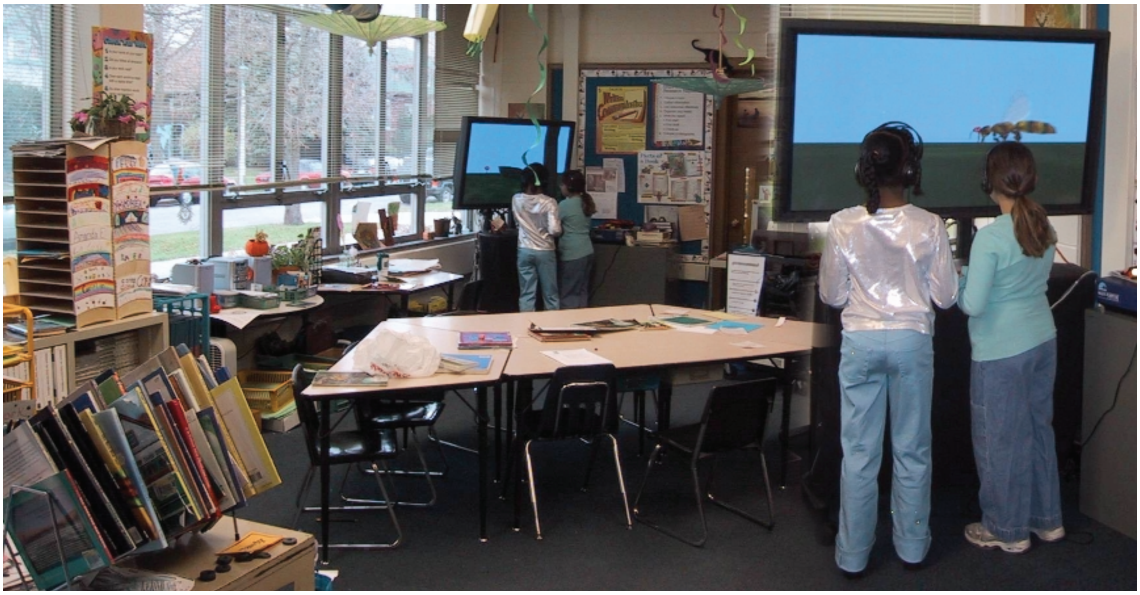
Explorations of the field follow a general pattern. A small group of students visits the field as a scouting team and reports back to the entire class on what they found there. The students are then given a question to answer, and they discuss how to explore the space and what data to collect to answer that question. The teacher will then break the class up into small groups that will each spend from 20 to 60 minutes exploring their part of the field at the ImmersaDesk. Sometimes the students collect their data with pencil and paper, other times they use laptop and handheld computers. (The students seem equally at ease with low-tech and high-tech data collection tools.) Finally, the class meets again as a group to aggregate their data, look for patterns, come to some conclusions, and report those conclusions. For each student, interacting with the technology is less than a quarter of their time in this unit; most of the time is spent in the whole-class discussions.

We've been using variations of the Field on the ImmersaDesk at Lincoln Elementary since spring 2000. Jarvia Thomas' second graders investigated similarities and differences and produced drawings and descriptions of the plants they found. Victor Baez's fourth graders learned about interpolation and extrapolation and created graphs of different plants' growth rates. Marilyn Rothstein's sixth graders learned to develop co-occurrence rules for different plants that grow together. Joanna Peterson's sixth graders learned how to estimate population distributions while creating a field guide. Kevin Harris' sixth graders looked for causal relationships for differential growth patterns in the plants. A Java application lets us quickly reconfigure the number and positions of the plants in the field to support this variety of activities.

The Bee Dance

In the Bee Dance application, we give the children access to a virtual world in their classroom without any obvious task, except to observe and try to understand the phenomena. In this world, the user is the size of an insect, sharing a small field with two bees. The first bee does a simplified version of the bee dance to tell the second bee which flower to go to. As with the Field, the students have limited controls. They can fly around this smaller field, and when they press a button on the wand, the second bee will fly off to the appropriate flower. When the second bee returns, the first bee will pick another random flower to direct the second bee toward. Once the students figure out that there is a gestural language, and the components of that language, they will be able to predict where the second bee will fly when they press the button.

We leave the application running on the plasma panel in their classroom for several weeks. We include a screen-blanker that darkens the screen after 10 minutes of inactivity so it doesn't interfere with the regular lessons. The children write their observations and their



2 Two third graders dancing with the bees on a plasma panel in the corner of their classroom.

3 In the Bee Dance application, children try to decipher the bee's gestural language.

questions on note cards and post them on a board next to the plasma panel for the rest of the class to see. The teacher tries to give appropriate hints so that the students can focus their observations but still make the discoveries themselves. While the Field stresses planning, data gathering, and data visualization, the Bee Dance stresses long-term observation and guided inquiry.

So far Diane Conmy's third, Victor Baez's fourth, and Betty Smitherman's sixth grade classes have danced with the bees (see Figure 2). Initially, the children focus on the technology; they are impressed by the display's size and clarity and the unusual input device (the wand). The older children tend to be less impressed and even critical. In the next stage, the children focus on discovering the interaction inherent in the application. They learn that they can fly around the space and that pushing a button makes the second bee fly. They learn, to their disappointment, that doing the things they usually do in computer games (such as bouncing on the flowers) doesn't cause miraculous events.

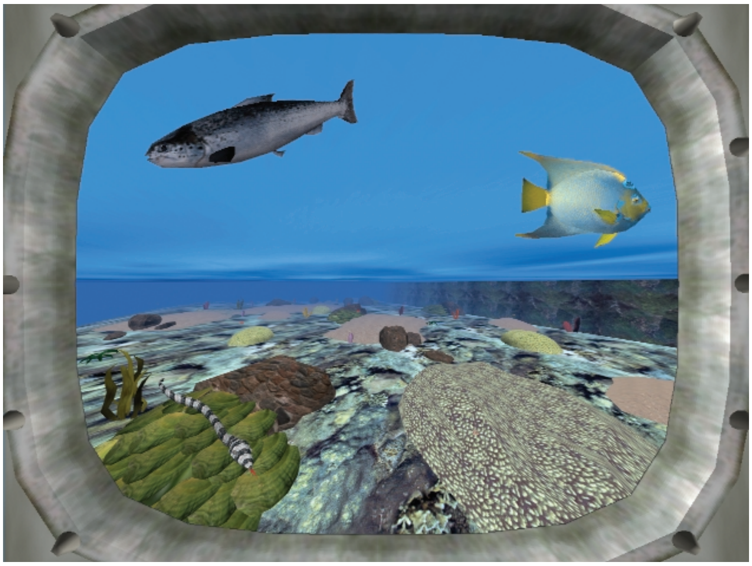
"This doesn't do anything," they say. This is the ideal moment for the teacher to give some hints. For some kids, it's enough to point out that the way nature works isn't always obvious, and sometimes we have to look closely at what's going on to discover a pattern. For others, a more direct clue is a question: Do bees communicate? Once a few children in the class begin to accept that there is a phenomenon worth investigating, a second wave of more intense interest and use of the application begins.

At this point, many students try to uncover the bees' behavior as they would in a computer game. In one case, two sixth graders spent a half hour recording the sequence of flower visits on the assumption that they could discover a systematic pattern. Finally, most children accept the simulation as a (more-or-less) realistic depiction of a natural phenomenon and focus on the bee's movements as the basis for communication (see Figure 3). Interestingly, the children's prior knowledge of bees often lies dormant until this final stage, when it occurs to them that they already have heard about bees dancing. At this point, knowledge tends to spread rapidly through the class as everyone wants to "get the answer to the puzzle."

Reaction

The teachers and parents at Lincoln Elementary have been very supportive of these activities. The children have also been enthusiastic, even when it becomes clear that data collection and careful observation is hard work. Several teachers have told us that this work has engaged children that were ordinarily more reluctant to participate. Diane Conmy said that "some of the very brightest and some of the very lowest join together over the screen, and they are made equal by it, which is what I love most about it. Some of my kids that receive extra help throughout their school lives with reading and math find the most enjoyment because they do not need anyone to help them here, they are free to discover. They like that their thoughts are valued."

The technology helped make science into a personal quest for the children. It was important to the various groups that they did the best job of collecting data, and they gained an appreciation for careful observation. The children developed confidence that they could actually perform a real science research project. Mathematical concepts became real and purposeful in the real world, and perhaps because of that, the children seemed better able to apply those concepts in later lessons.



4 The shallow region of the new undersea environment contains many different types of creatures to observe.

5 Our current work focuses on augmenting the Field with wireless handheld displays to aid data collection. Here the handheld works as a global positioning system receiver letting the student accurately record the positions of red and white flowers.

Current directions

We are currently working on a new undersea environment that will let the students board a small submersible and travel from a shallow coral region down a cliff to 15,000 feet beneath the surface (see Figure 4). They can observe the behavior of different types of marine life near the surface and in the depths of the sea and take various readings (such as depth, pressure, temperature, salinity, and light level). This also raises interesting questions about how to count populations that constantly move in a 3D environment.

We're continuing to augment our big displays with several smaller networked displays—laptops, handhelds, and tablets. This way, the large screen of the ImmersaDesk or plasma panel can show the virtual world being explored while the smaller displays act as computerized tools to aid in the data collection. These smaller displays also help spread the work over the several students in the group; each child has a particular task to perform and an associated display to interact with. In the Field, the laptop may show a global positioning system map of where the team currently is or has been in the past, and students can use the handheld for data entry (see Figure 5). In the undersea environment, one laptop shows various gauges while another acts as a small fish tank where students can temporarily capture creatures to study them in detail.

We plan to continue this partnership with Lincoln Elementary in these and other projects for the foreseeable future. ■

Acknowledgments

We thank the following staff and students at the Electronic Visualization Laboratory: Janet Kim, Jason Leigh, Dave Pape, Greg Dawe, Alan Verlo, Tim Portlock, Melissa Golter, Kyoung Park, and Brenda Lopez Silva. We also thank the students, staff, and teachers at Abraham Lincoln Elementary School. The National Science Foundation's GK-12 and ITR grant programs supported this work.

Readers may contact the authors at the Electronic Visualization Lab., Dept. of Computer Science M/C 152, Univ. of Illinois at Chicago, Chicago IL, 60607, email aej@evl.uic.edu.

Readers may contact the department editors by email at rosenblu@ait.nrl.navy.mil or Michael_Macedonia@stricom.army.mil.