Learning Science Inquiry Skills in a Virtual Field

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Abstract

Sixth grade students at Abraham Lincoln Elementary School explore a virtual field via an ImmersaDesk and collect data there using hand-helds computers. Back in the classroom they integrate their data, visualize it to see the patterns that emerge, and then propose explanations for these patterns. The goal is to help the students learn science inquiry skills within an environment that encourages their formation.

Keywords
Collaborative Virtual Environment, Education, Visualization

1. Introduction

Teachers rely on local environments to give students something to observe and measure - collecting leaves in a field, measuring the acidity of a stream, or surveying the height of a hill. Local environments have the advantage of being local, and being real. However they also have three important drawbacks: they may emphasize activity over learning [1], they may limit the domain of inquiry, and they may constrain teachers' ability to scaffold learning by reducing complexity.

We believe that learning how to conduct an investigation within a virtual world can be beneficial in preparing students to conduct these investigations in the real world. The students can explore environments that are not locally accessible and measure phenomena that they can't physically measure. More importantly, the teacher can simplify the complexity of the world to focus on particular features.

Whether the students collect data from the real world or a virtual world, they need to be able to effectively visualize and analyze the data that they have collected. Pencil and paper and the ever-present blackboard are the typical options available. They are valuable for small data-sets but quickly become cumbersome with large amounts of data. Scientists use computers for this job and we would like to expose the students to this. However tools that work well for scientists won't work well for schoolchildren. As with using VR for exploration, we need to simplify the tools just as we have simplified the problem.

This collaboration links the Virtual Reality (VR) educational work at the Electronic Visualization Laboratory (EVL) in the Department of Computer Science at the University of Illinois at Chicago with the desktop educational work at the School of Education and Social Policy at Northwestern University. It is part of a larger NSF funded project including the University of Michigan and Georgia Tech seeking to develop explicit guidelines and an engineering process to support software developers in building effective computer-based learning environments. We want to be able to swap 'components' in and out so that data can be collected in the real world, or from a virtual environment or from a pre-existing datastore. Similarly the students may do the actual data collection with a computer, or pencil and paper. They may visualize their results with a computer or blackboard. Changing these components doesn't affect the structure of the overall activity, but it will affect the kind of work the students can do and the type of assistance that the students can receive at each stage.

Section 2 describes Abraham Lincoln Elementary School and the VR equipment that we have installed in the school. Sections 3 and 4 go into detail about the learning activity. Section 5 talks about what we learned from this study and section 6 describes our plans for future work.

2. Abraham Lincoln Elementary School

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. It is a large school (620+ students), nearly always allocating four classrooms at each of the K-6 grade levels. Besides a racially and economically diverse student body and faculty, Lincoln offers diversity of subject mastery. 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. Since the study described here, Lincoln has become a K-5 elementary school with the sixth graders moving to the new middle school.

We have been working with Abraham Lincoln Elementary School in Oak Park Illinois since December 1998 when we moved an ImmersaDesk in as part of our work using VR to teach young children about the shape of the Earth. Over 500 students have used the ImmersaDesk at Lincoln with a variety of educational environments [5].

This experience at Lincoln has taught us that just being in the school isn't enough – we need to be in the classroom. In the spring of 2001 we augmented the ImmersaDesk with a mobile cart consisting of a 50" plasma panel driven by a Linux PC, with an additional PC to handle tracking. We lose stereo visuals and typically do not do head-track with the plasma panel, but we retain hand tracking (allowing the students to point in three dimensions), audio, and the ability to support small group work. This technology also has the advantage of being an order-of-magnitude less expensive than an ImmersaDesk, and employs consumer-driven commodity technologies.

3. The Activity

We have been focusing our efforts on young learners and science inquiry skills. What should young learners know? The Illinois Learning Standards for Science state that students should "understand the process of scientific inquiry and technological design to investigate questions, conduct experiments and solve problems."

In early elementary school students should be able to:
- Describe an observed event
- Develop questions based on scientific topics
- Collect data for investigations using measuring instruments and technologies
- Record and store data using available technologies
- Arrange data into logical patterns and describe the patterns
- Compare observations of individual and group results

In late elementary school students should be able to:
- Formulate questions on a specific science topic and choose the steps needed to answer the questions
- Collect data for investigations using scientific process skills e.g. observing, estimating, and measuring
- Construct charts and visualizations to display data
- Use data to produce reasonable explanations
- Report and display the results of individual and group investigations.

Combining EVL's virtual environments work with Northwestern's MyWorld allows us to help the children learn these skills in a controlled environment. At the same time we learn about how to provide appropriate aide to the children while they are engaged in these activities.

Initial Whole-Class Discussion: In this activity the sixth graders play the role of a team of scientists in an ink company that gets their ink from fields of red plants. The company would like to increase the number of red plants growing in this field. The students are to find out why there seem to be more red plants in some areas than others, and give recommendations for increasing the number of red plants.

We introduce this scenario in the classroom and then show them the Field on the plasma panel. See Figure 1. The students see what the Field looks like and how to move around it. They notice that there are both red flowers and white flowers growing in the Field. They also get a feeling for the size of the space they need to explore. Based on this brief visit to the Field the students are asked how they would systematically survey this large space. Several different 'lawnmower' algorithms are proposed. The students are also introduced to the PocketPC based GPS receiver and data collection tool that they will use. Mr. Harris, their teacher, then breaks them into nine groups, one per sector, and over the next two days groups of two or three are pulled out of class to visit the Field.

Much of the activity in elementary schools is organized around small groups of children rather than individual work. Children's play experience with game consoles at home (Playstation2, X-box, GameCube etc) suggests a similar model with a small group of children with shared control sitting around a relatively large display. We adopted a similar model for our work with small groups visiting the Field together.

The Field: The Field is a square patch of flat ground 3000 feet on a side. It is divided into regions in two ways: picket fences divide the space into a 3x3 grid, and different patches of terrain divide the ground into regions of grass, sand, and gravel. Within this field there are trees, rocks, and plants. The Field was designed to be big enough that you could not stand in the center and see all of the important details, but not so big that you couldn't survey the space within a reasonable time. The various groups of students take anywhere from 30 minutes to 60 minutes to explore their sector.

The Field has limited affordances. The students can move around on the surface and plant flags at points of interest, allowing them to mark flowers that they have already counted. In some studies we allow the students to take 'snapshots' of the space. Classrooms are usually broken into groups of two to four students each to visit the Field. Usually we break up the field geographically for the various groups with each group taking one of the nine sectors, but we have also broken up the Field temporally with each group visiting the Field in a different virtual month to see the growth rate of the plants.

We have used variations of the Field on the ImmersaDesk at Lincoln since the spring of 2000 with second, fourth, and sixth grade classrooms. The 2nd graders investigated issues of similarity and difference. The 4th graders learned about interpolation and extrapolation. The 6th graders learned to develop co-occurrence rules and to estimate population distributions.

The children have no direct control over what is happening in the Field. Nothing that they do in the Field will affect the underlying simulation. We imposed this constraint to reduce the cognitive burden of exploring the space and limiting the students to familiar activities [3, 4, 6]. This still allows the students to articulate and investigate hypothesis, but like Astronomy, the students can't manipulate the variables of the study.

Displays: The students use several different displays while collecting their data. The main display is the ImmersaDesk showing the Field. One of the students holds a Pocket PC showing the GPS position and orientation of the group. The Pocket PC also acts as a data entry tool where the student can click on the icon of the plant they have found and automatically record its coordinates. The students also have two laptop computers. The first shows a top-down view of the Field where the students can see the path they have taken. The second is the interface they will eventually use to analyze the data, MyWorld, which shows the plants that they have found. See Figures 2, 3.

We could have placed any or all of the various displays we use in this study onto the ImmersaDesk screen. There are two reasons why we didn't do this. First, we wanted to strengthen the illusion of being in the Field by only showing the Field on the ImmersaDesk screen. Second, the multiple displays give the multiple students different things to interact with and 'possess' as part of their 'job' in the survey.

Another option was to place virtual measuring devices into the Field, much as the students plant flags in the space as markers, and then read off the resulting measurements. We decided instead to go with the 'tricorder' metaphor of reading the data off of the Pocket PC because we have previously found that students have a hard time making the sorts of precise movements in the virtual world that would be required to accurately position measurement devices.

Working in the Field: We designed the Field to be viewed by multiple students simultaneously. Based on our previous experiences with educational VR environments we knew that giving one child control meant that the child with control tended to be more engaged with the educational content and tended to learn more, while the children that were 'along for the ride' tended to learn less [7].

Some of the solutions to broadening engagement are technical such as splitting a single generic control into multiple controls with specific functions, but we believe that more of the solution lies in the way the learning experience is structured. For small groups there are several ways to broaden engagement:

- pass full control regularly between the children
- divide control between the children, giving each child a particular role

- divide control between the children rotating the roles at regular intervals

With the Field we have chosen the third option of having multiple roles that the children rotate through. In previous work with the Field one child would 'drive' using the wand, another would write down what they found on a piece of paper, and a third would navigate by looking for things in the virtual environment. The driver was clearly the most sought after role. This time the roles were more even. The driver had the wand; the person collecting data had the Pocket PC; and the navigator had the display showing where they had already been. All of the students could see all of the displays but each had to focus on one to accomplish their group task.

4. Analyzing Data Back in the Classroom

Once all of the groups had collected their data, we moved the plasma panel back into their classroom and used it to show both MyWorld, the tool to analyze the data, and the Field. MyWorld [2] is a Geographic Information System (GIS) written as part of a research program to adapt data visualization and analysis tools to support inquiry learning for students in middle school through college. MyWorld is designed to provide the essential features of a professional GIS environment through a supportive interface designed with the needs of students and teachers in mind. Using MyWorld we took the data from each sector that the students collected and put it together in a single display showing the positions of the red and white plants.

When we set up the positions of all of the flowers in the field there were two effects that we wanted the children to see. The first is that in the entire field the red and white plants are evenly dispersed except for an obviously circular cluster of red flowers in one area. This feature couldn't be seen while exploring the individual sectors but is very apparent when viewing all the sectors together. The children had several suggestions about what could cause this: chemicals, insects, fertilizer, etc. They decided that it would be a good idea to take a look at what was at the center of the circle. Switching over to the field on the plasma display we walked over to that area and found a beehive that some of the students had seen during their survey but hadn't remembered. The students came to the conclusion that the bees were pollinating the red flowers and helping them take over that area of the Field.

The second effect was that there are more flowers towards the southern end of the field. The children came up with several possible causes. We focused on two – moisture content of the soil, and salinity. Our initial plan was to have the students go back into the Field with another probe to take moisture and salinity readings at regular intervals and then visualize those readings along with the plant distributions. Unfortunately we ran out of time at the end of the school year so we showed them what the collected moisture and salinity data would look like in MyWorld. The soil moisture had a gradient that was orthogonal to the plant density, while the salinity matched. Figure 4 shows three screens from MyWorld used during this discussion.

The students' final recommendations were to buy more beehives to plant around the Field, and if possible trade the land in the north for more land in the south.

5. Reaction

We needed to place enough plants in the space to ensure that both patterns (the bees and the salinity) were noticeable. This meant placing almost 550 plants into the space – 30 plants in each of the northern sectors, 60 in each of the central sectors, and 90 in each of the southern sectors. The groups in the northern sectors spend roughly 20 minutes to collect their data, those in the central sectors 40 minutes, and those in the south 60 minutes. The children were allowed to stay until they felt that they had completed their survey. We did not set a time limit.

The children did not have any trouble using any of the technology. We had not seen the children having any trouble using the ImmersaDesk but we thought that they might have troubles using the Pocket PC. They didn't. We showed them how to read the display and how to record a flower position and they took it from there. They also had little trouble integrating the different views presented by the different devices.

The children were enthusiastic both during the in-class discussion and during their exploration of the Field – even when it cut into their recess time. Previously we had found that while second graders found the field very interesting, sixth graders tired of it quickly. We believe the addition of the extra displays kept all the children busy and interested. The children were very good about switching roles on their own. Again, we believe that the additional technology made each of their roles interesting. After helping the students to get into their correct sector, we generally tried to stay away from the action at the ImmersaDesk.

In addition to recording the children's actions on videotape, the computers were also keeping track of their actions. This is an advantage over doing this same kind of survey in a real field. Figure 5 shows the actual positions of all of the red and white flowers as well as the positions that the students marked. Overall the students did quite well with the groups finding and marking roughly 90% of the plants in their sector.

Most of the students were careful in placing their flag and recording their data close to the plant. A few (tending to be more boys than girls) preferred to zoom through the environment at high speed, barely slowing down as they passed by a flower to drop a flag and have their friend note the plant on the Pocket PC. In the context of this experiment that imprecision didn't affect the results, but it would (and should) affect a more careful survey of the field. We tried to encourage good surveying techniques during this excursion, but at the same time we realized that this could be a good learning experience showing how sloppy data gathering leads to sloppy results. The quality of the results was important to the children, at least to the extent that they were very interested in knowing which group did the best job, so there was incentive to do the job well.

The most common reason that the students missed a flower was that they didn't do a thorough survey. Even though the students articulated several different lawnmower algorithms in the class, very few groups implemented such a strategy. Several groups used the laptop map to see what areas they had missed and then tried to 'fill in' the blank spaces. Figure 6 shows the paths that the various students took during their explorations.

One of the reasons that we implemented a computerized data collection system in this study was that we previously used pencil and paper with poor results. The children have had very little experience with collecting data and in previous studies they lost or altered a great deal of data while writing it down. Here it was very important for the students to see the appropriate effects in the visualization so we wanted to minimize these kinds of errors.

We believe that this study had several benefits for the children involved. The teachers in this and other courses said it made mathematical concepts real and gave them a purpose in the real world. The children developed the confidence that they could actually perform a real science research project and gained an appreciation for the importance of careful observation. The study also engaged children who are ordinarily less reluctant to participate.

6. Current Directions

In the time since this study was performed we have switched over from the ImmersaDesk to a brighter, more portable, less expensive GeoWall (sub $10,000 Linux/Windows/Macintosh based passive stereo display – www.geowall.org) as our primary display at Lincoln. One of the main features of the ImmersaDesk is its ability to do head-tracked stereo graphics for virtual reality. Since we typically had several students standing in front of the ImmersaDesk, we typically turned the head-tracking off, and fixed the viewpoint for drawing the stereo imagery. This meant that we could switch to the GeoWall without losing any capabilities for this research. This switch allowed us to switch from active-stereo glasses costing several hundred dollars per pair to plastic or paper glasses costing less than $2.00 per pair. It also allowed us to switch from using the ImmersaDesk's 'wanda' input device to a PC game controller that is more familiar to the students. As the GeoWall, like the ImmersaDesk, is a projection-based system, it still takes up a fair amount of space so we are continuing to use the plasma panel to roll into classrooms. We used a GeoWall driven by a Macintosh G4 tower in the second iteration of this study, and used eight PC and Macintosh laptop computers in the classroom for the third iteration of this study.

In this first iteration where the students collected data on the ImmersaDesk, the students analyzed the data using MyWorld as a class on the plasma display. The students we able to use MyWorld effectively, so in the second iteration where the students collected data on the GeoWall, the students analyzed their data using MyWorld in their own groups using laptop computers before coming together as a class to discuss the results. See Figure 7. In the third iteration, where the students used laptop computers to walk through the field, the students used those same computers to analyze the data in their groups with MyWorld. See Figure 8. Use of the laptops to explore the field allowed us to cut the time for that part of the work down dramatically, since all of the groups were exploring at the same time. However since there were more distractions from the other groups, the children using the laptops were less focused during their data collection than the groups using the ImmersaDesk or the GeoWall.

We also want to allow the children to do more interesting tasks. We now have turtles that can wander slowly around the Field making them harder to count than the static flowers. We have also developed an application allowing them to go underwater in a shallow coral reef and then dive very deep into the ocean along an undersea cliff where they can see the different forms of life as they go deeper and deeper. This world was first tested with 6th graders in the spring of 2003. See Figure 9.

We also want to look at varying the experience for different groups – some using the Pocket PC to collect the data, some paper, and others collecting the data from a desktop database. We also want to investigate whether the skills learned here in the virtual world transfer to the real world by having the children conduct a similar study out in a real field.

The Field application itself has also evolved into an application designed to help teach undergraduate Earth Science students in college. This application, walkabout, allows instructors and students to map various images (satellite photos, aerial photography, elevation maps, etc) onto 3D terrain and then walk over that terrain to help them learn the relationships between 3D terrain and its various 2D representations.

7. Acknowledgements

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ImmersaDesk is a registered trademark of the Board of Trustees of the University of Illinois.

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Figures

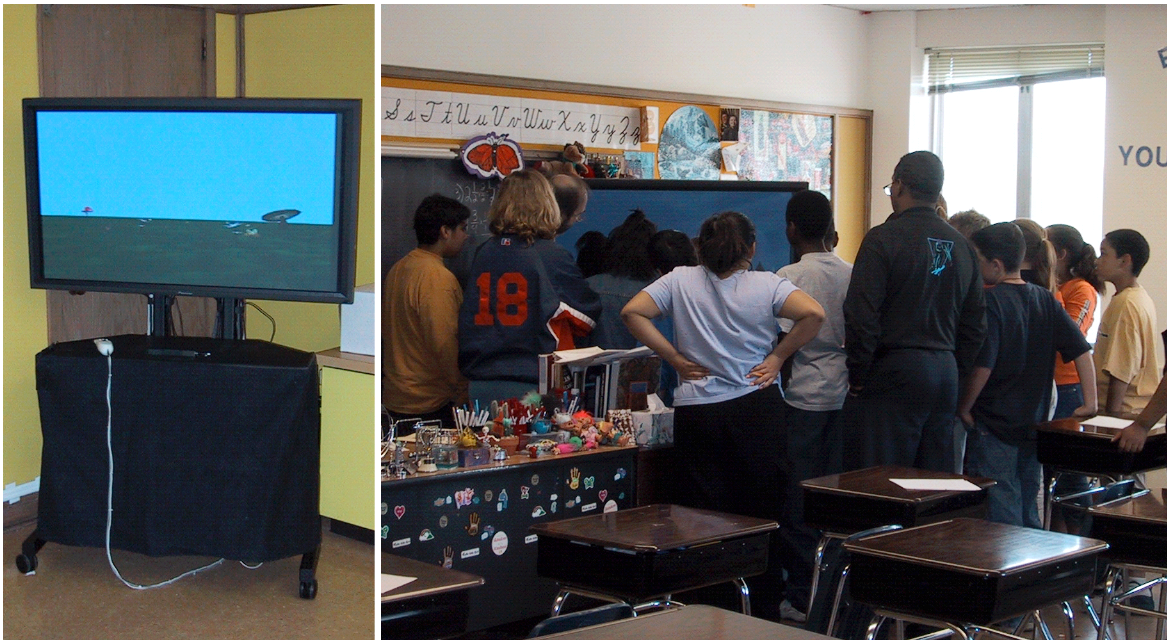

Figure 1: For the in-class discussions we displayed the Field on a PC-based hand-tracked monoscopic plasma display that we moved into the classroom.

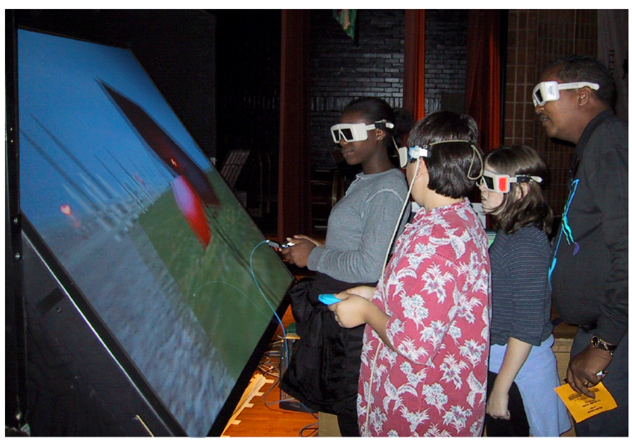

Figure 2: Sixth grade teacher Kevin Harris watches as three of his students explore their sector of the field. One student drives the group through the space with the Wanda; another records the flowers they find using the Pocket PC; the third tracks their progress on a laptop.

Figure 3: Aside from the ImmersaDesk, the students view three different displays during their survey. The Pocket PC acts as a GPS system showing the students' location and orientation in the Field as well as giving them the ability to record the plants that they find. The laptop map interface allows them to see where they have been. The laptop MyWorld interface allows them to see what plants they have found, and lets them see the interface they will use later to analyze the data.

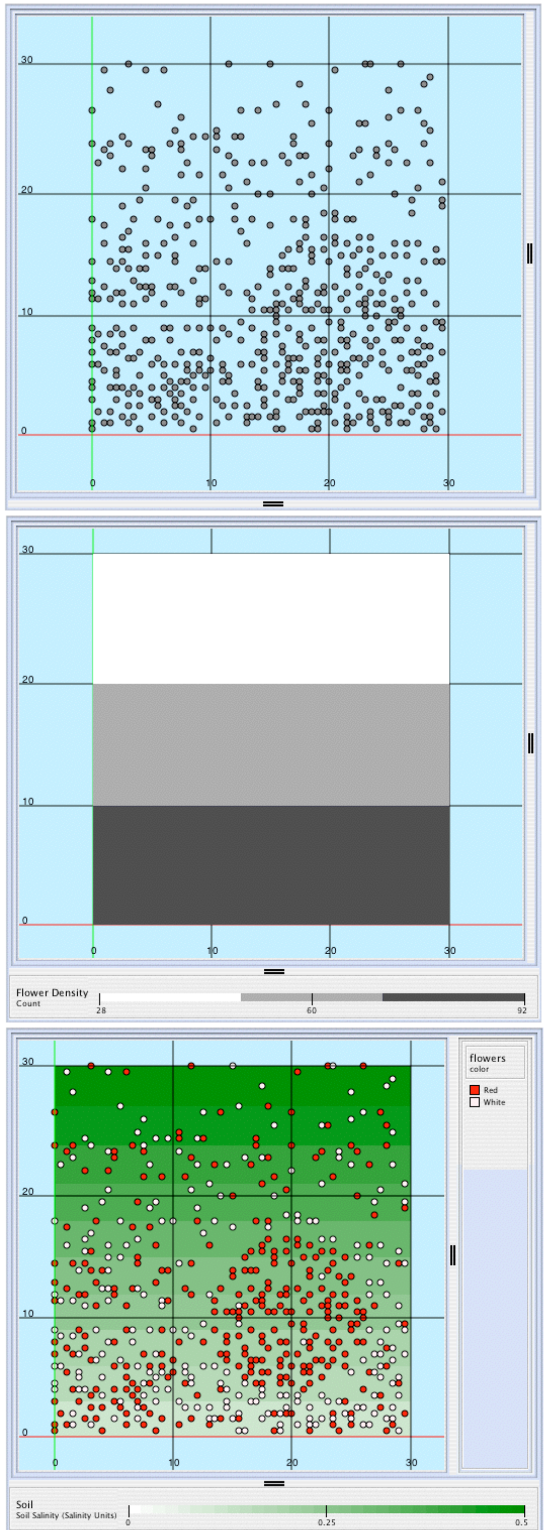

Figure 4: Using MyWorld the class can integrate the data they collected and apply transformations. For example, the students can view all the plants regardless of colour (top), then look at the density of the plants (middle), or compare the plants to the salinity of the soil (bottom).

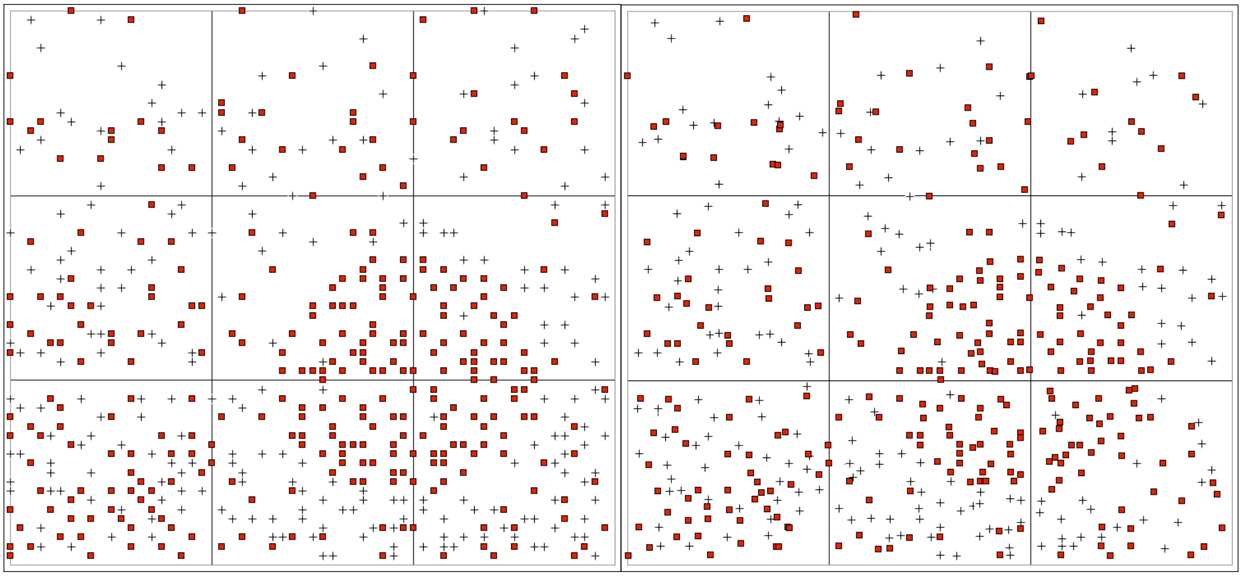

Figure 5: The image on the left shows the plants that were placed in the field. The image on the right shows the plants that were found by the students. Red plants are marked with boxes, white plants with crosses. The students found roughly 90% of the plants.

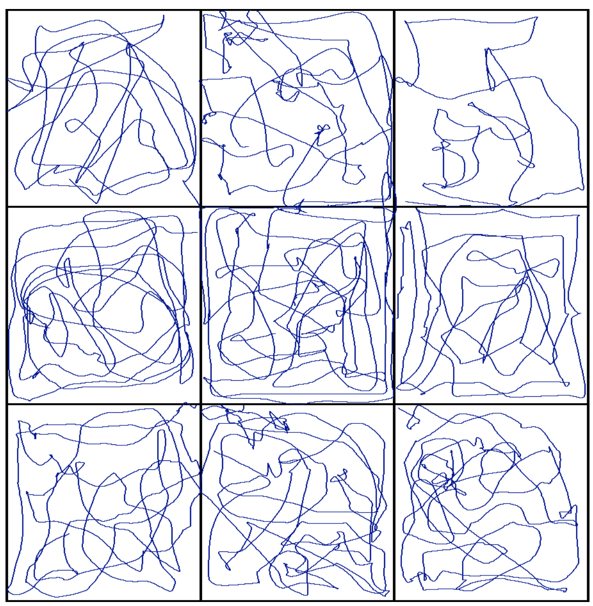

Figure 6: This image shows the paths that each of the groups took as they explored their sector. While the class thought a 'lawnmower' approach would be effective, none of them actually implemented this strategy.

Figure 7: In the second iteration of the study the students explored the Field using a passive-stereo GeoWall driven by a Macintosh G4 tower. One student drives the group through the space with a game controller; another records the flowers they find using the Pocket PC; the third tracks their progress on a laptop.

Figure 8: In the third iteration of the study the students explored the field in a classroom using laptop computers to display the field, but still used Pocket PCs to record their data.

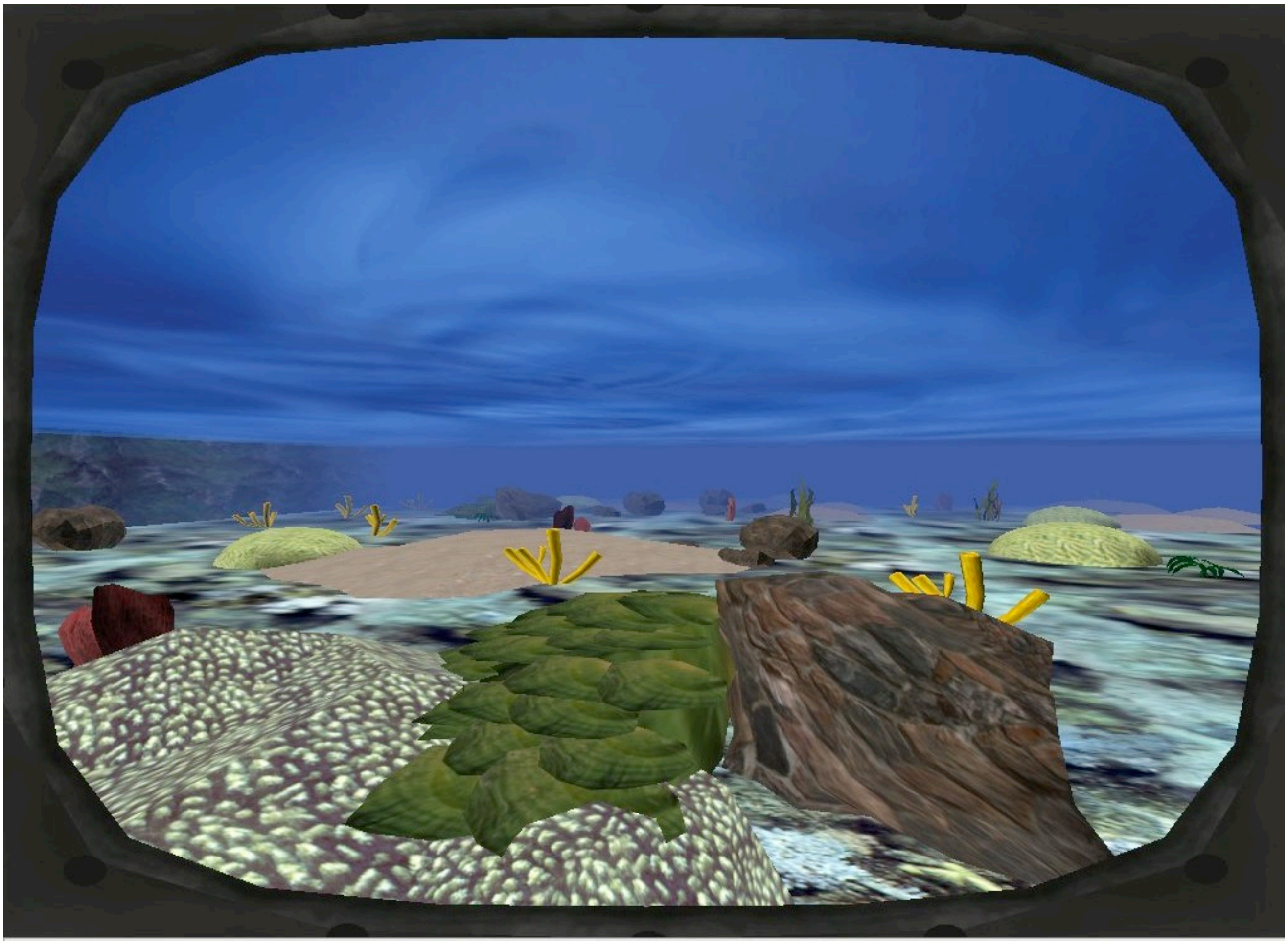

Figure 9: A new world we are now using is this underwater environment that includes mobile fish and other creatures at both shallow and deep depths.