# Making Visualization Accessible to Students

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## Scientific Visualization for Learning

Scientific visualization technologies have had an enormous impact on the geosciences. Visualization as a technology for both investigation and communication has become almost ubiquitous. It is difficult to walk into the office of a geoscientist or open the pages of a geoscience journal without finding a computer-rendered visualization of scientific data. However, if you were to walk into a classroom, dorm room, or laboratory where students are working on their homework for a "geo" class, the odds of finding them constructing or analyzing visualizations the way scientists do is extremely low. Recognizing the potential value of scientific visualization as a technology to support science learning, we have been engaged for several years in the development of tools to make visualization and data analysis accessible to learners.

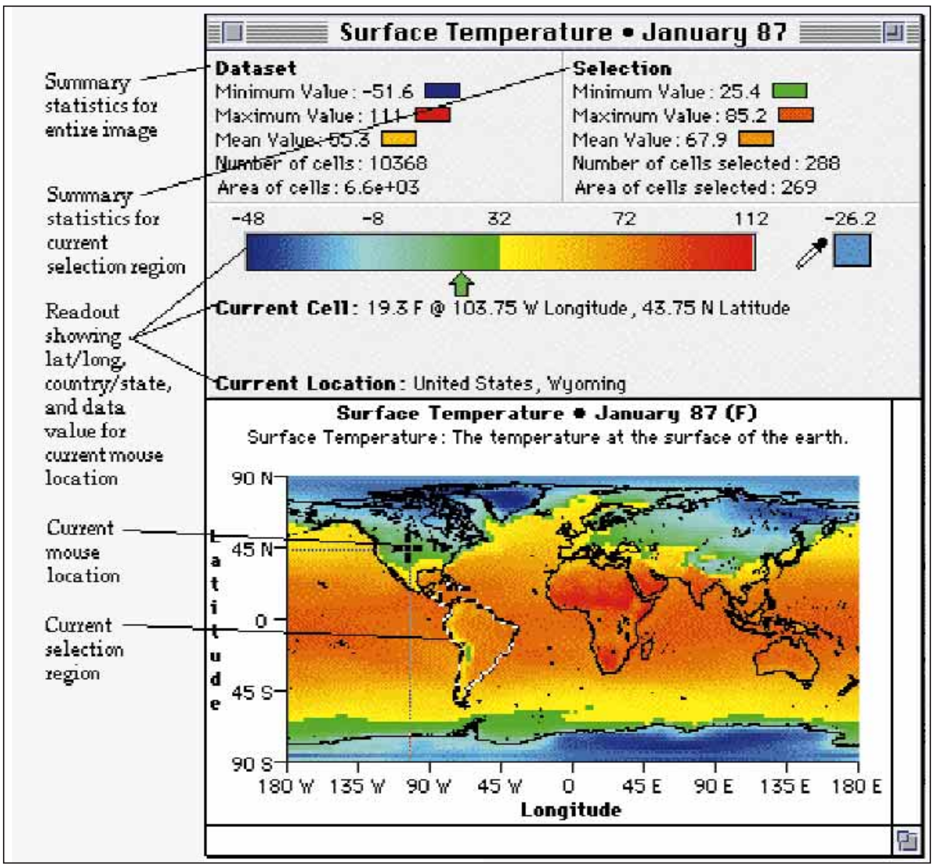


Figure 1. A WorldWatcher visualization window.

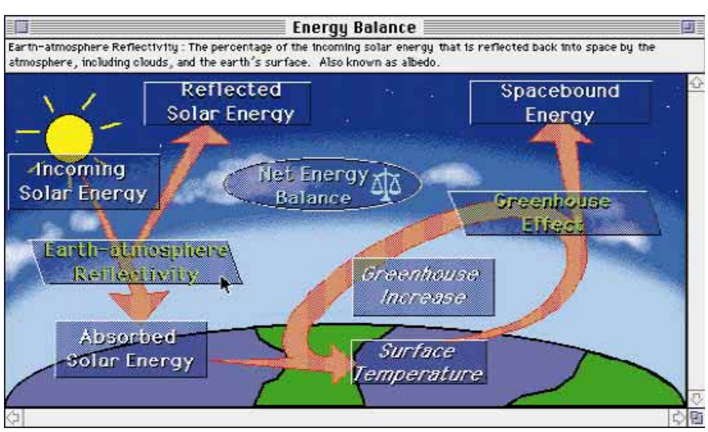


Figure 2. A WorldWatcher diagrammatic interface to a library of data illustrating Earth's energy budget. Clicking on any variable name in the diagram brings up a list of dates to select.

Visualization offers great promise for education (Gordin and Pea, 1995) for several reasons. The same advantages that scientific visualization offers to scientists also hold for students. Visualization exploits the power of the human visual system for finding patterns in imagery, allowing an individual to interpret data visually, without requiring sophisticated mathematical operations. Therefore, visualization can remove mathematical skills as a gatekeeper to working with scientific data. As a technology for scientific investigation, visualization provides the opportunity to engage students in authentic inquiry as part of the learning process. Participation in meaningful inquiry is increasingly being recognized as a critical component of science education, as evidenced by the prominent role of inquiry in the national science education standards (National Research Council, 1996). Inquiry activities allow students to better understand the practice of science and interpret the results emerging from scientific research. "Literacy" with visualization has become an important skill for both practicing scientists and informed citizens. On the one hand, the use and manipulation of visualization is growing across a broad range of scientific disciplines, as well as mathematics, information processing, and finance. On the other, images and animations produced through the techniques of scientific visualization are becoming increasingly common in both the print media and on television.

It hasn't been easy to bring visualization into the classroom, even if you have the appropriate technology infrastructure. If you are an earth or environmental science teacher at the secondary school or college level and you want to give your students the experience of working with scientific visualization, you have historically faced a frustrating choice. You can either teach your students how to use one of the powerful, general-purpose visualization tools used by scientists, or you can have them view visualizations with an image viewer. Teaching students to use scientists' tools is difficult, if not impossible, to do with many populations of students and consumes precious time that any teacher would prefer to devote to learning science. On the other hand, image viewers, while they are easy to use, only allow students to view visualizations constructed by others, not to construct, customize, or manipulate them themselves. In other words, they do not allow students to work with visualizations in the way that scientists do. Recognizing the unsatisfactory nature of both of these alternatives for most teachers, we set out to create a visualization environment for geographic data that is designed specifically for students. Our goal was to create a software environment that provides the power of scientists' tools for the creation and customization of visualizations and the analysis of data, while providing the support and structure necessary to make these operations accessible to students at the high school and college level. Through a three-year, NSF-funded educational research project, we developed a geographic visualization and data analysis program, called WorldWatcher, that achieves this balance. WorldWatcher has been used successfully in middle schools, high schools, and colleges, requiring no more than 45 minutes of use to master its primary capabilities.

### WorldWatcher

WorldWatcher is a tool for the visualization and analysis of gridded, geographic data (Fig. 1). The design of WorldWatcher has been focused on understanding the supports required by learners to enable them to engage in meaningful investigations with geographic data.

To support meaningful inquiries, we determined that a visualization environment must support the following operations:

- Customization of visualizations. In order to interpret data effectively through visual representations, learners must be able to customize those representations to highlight important patterns in the data. In WorldWatcher, users are able to modify the colors used to represent values, the range of values displayed, the spatial resolution, and the magnification of an image.
- Quantitative analysis of data. While a visual representation can dramatically improve a person's ability to interpret data, it is not a substitute for quantitative analytic techniques. WorldWatcher provides tools for simple statistical and arithmetic operations on data. It also allows users to identify specific regions within visualizations by specifying selection criteria.
- Alternative representations. Different representations of data can support different forms of analysis. Therefore, WorldWatcher provides multiple geographic projections for data, as well as alternative representations such as histograms, line plots, and scatter plots.
- Record keeping and documentation. Conducting a successful investigation requires that students be able to maintain records of their work. WorldWatcher provides a notebook facility that allows students to record their activities in the form of text, images of visualizations, and hypermedia links to data. This same notebook facility is used to provide documentation for the data and operations available in WorldWatcher.

These four criteria are not unique to a tool for students. They reflect the requirements for supporting inquiry and apply equally to scientists' tools. However, the goal of supporting science learning adds additional criteria. Because students lack the background knowledge that scientists bring to their use of visualization tools, WorldWatcher is designed to provide the additional support students require

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(Edelson and Gordin, 1998). This support takes several forms. First, visualization windows provide contextual information including continent overlays, latitude and longitude markings, and an active readout displaying the current cursor location and underlying data values. Second, all data files in WorldWatcher are tagged with default visualization parameters that specify initial settings for the color scheme, range, units, and display resolution of the data. These default values enable learners to begin the interpretation of unfamiliar data without needing to identify appropriate visualization parameters first, as a scientist would. Third, WorldWatcher provides diagrammatic interfaces to its data libraries (Fig. 2). These diagrammatic interfaces play an important instructional role by visually illustrating the relationships among variables. Finally, WorldWatcher provides operations not found in scientists' tools that were created specifically to support educational activities. For example, WorldWatcher contains a facility that allows users to create new data using a paint program interface. This facility is used in learning activities in which learners "draw" maps to represent the state of their current understanding of a phenomenon or to represent hypothetical situations. WorldWatcher also allows learners to print out cut-and-fold images of two-dimensional visualizations that they assemble into three-dimensional polyhedral "globes."

In addition to support for students, the design of WorldWatcher takes into account the needs of curriculum designers and teachers. For example, the same notebook facility that allows students to record their work was designed to be used by teachers or curriculum developers to create electronic "handouts" for students. These handouts can contain instructions, background information, and direct links to data. WorldWatcher also provides a suite of tools to allow nonprogrammers to assemble new WorldWatcher data libraries, build diagrammatic interfaces to these libraries, and create documentation and default display parameters for the data in the libraries. These tools are designed to enable scientists and curriculum developers to write new WorldWatcher curriculum units around any collection of raster (gridded) data.

## Global Warming Curriculum

One of the primary curriculum development efforts for WorldWatcher has focused on the global warming controversy as a motivating context for earth and environmental science education. The Global Warming Project, designed in a partnership between teachers from the Chicago public schools and Northwestern University researchers, exemplifies our goal of integrating WorldWatcher into extended classroom investigations of real scientific issues. Lasting for six to eight weeks, the Global Warming Project places middle school and high school students in the role of scientific advisors to the secretary general of the United Nations, for help in finding out what the "global warming" issue really is about and what, if anything, should be done about it.

To accomplish this goal, students must investigate how Earth's climate works and how to detect any potential changes brought about by human activities. In a series of structured activities, students investigate the meaning of temperature change, the processes of energy transfer that control the climate on Earth, and the role of the atmosphere in maintaining Earth's climate balance. Along the way, students present a series of background briefings on their findings. At the conclusion of the unit, groups of students must each advise a specific nation about the risks that might accompany predicted global climate change, and they offer concrete, scientifically justifiable solutions for responding to or moderating these effects.

The Global Warming Project combines hands-on labs, class discussions, computer-supported investigations of global data sets, and simple climate models, with role playing and presentations in order to create a realistic setting for the investigation of hotly debated scientific issues. For example, in one set of activities, students conduct a traditional laboratory investigation of the effect of different colored materials on the absorption of light. They then apply the knowledge gained through this lab to global climate processes by investigating WorldWatcher data sets showing dominant ground cover, surface reflectivity, and absorbed solar energy for Earth. In the culminating activity for this part of the curriculum, they must combine these findings with other information about the Earth-Sun relationship, and—using graphs and scientific visualizations to illustrate their points—explain to the UN secretary-general the role that solar energy and physical geography play in determining surface temperatures. In other parts of the curriculum, students explore other relevant processes, such as the carbon cycle and the greenhouse effect, through similar combinations of computer-based and conventional activities.

## Acknowledgments

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## Alternates Receive 1998 Student Research Grants

Each year when the Committee on Research Grants selects student grant recipients they also select an alternate group of recipients in the event that some of the grantees return part or all of their funds because they have received funding elsewhere or have changed their research plans. As the returned funds become available, they are re-awarded by the Research Grants Administrator to the alternates named by the committee.

In 1998 ten alternates received funding following the initial awarding of grants. They are: Peter Sak, Pennsylvania State University; Ziya Cetiner, University of Idaho; Kelly Christin MacGregor, University of California, Santa Cruz; Molly A. Trecker, University of California, Santa Barbara; Sally L. Letsinger, Indiana University; Andrew J. Hooper, University of North Carolina at Chapel Hill; Christopher M. Jengo, Bowling Green State University; Shafiul H. Chowdhury, Western Michigan University; Yiqiao Zou, New Mexico Institute of Mining and Technology; Garret L. Hart, University of Wisconsin—Madison.