(Image)

Adapting Digital Libraries for Learners

Accessibility vs. Availability

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Digital Libraries: Good for Education?

One of the frequently stated goals of digital libraries research is to produce digital resources that can serve both the technical or research communities and the educational community. The National Aeronautics and Space Administration (NASA), for example, has a number of ongoing efforts to make their extensive on-line databases of remote-sensing data into a valuable resource available to educators at all levels. In this article, we will examine the reasons this might be a worthy goal and then discuss the challenges involved in making digital libraries designed for scientists useful for learners.

The first question to ask about these efforts is, *why would they be good for education?* Take Figure 1, for example. It was taken from a web site maintained by the Lamont-Doherty Earth Observatory at Columbia University, and it provides an interface to remote sensing data in the form of 2-dimensional scientific visualizations. Why would such a digital resource be useful for learners? Some of the reasons this networked digital resource could be valuable are: 1) students could investigate authentic scientific questions using real, complex data; 2) students would have the opportunity to study their world in order to explore policy options; 3) the activities that these resources support could help students to develop a view of science as inquiry unlike more conventional classroom activities; and 4) resources such as this can provide students with a common ground that links them to the community of practicing scientists.

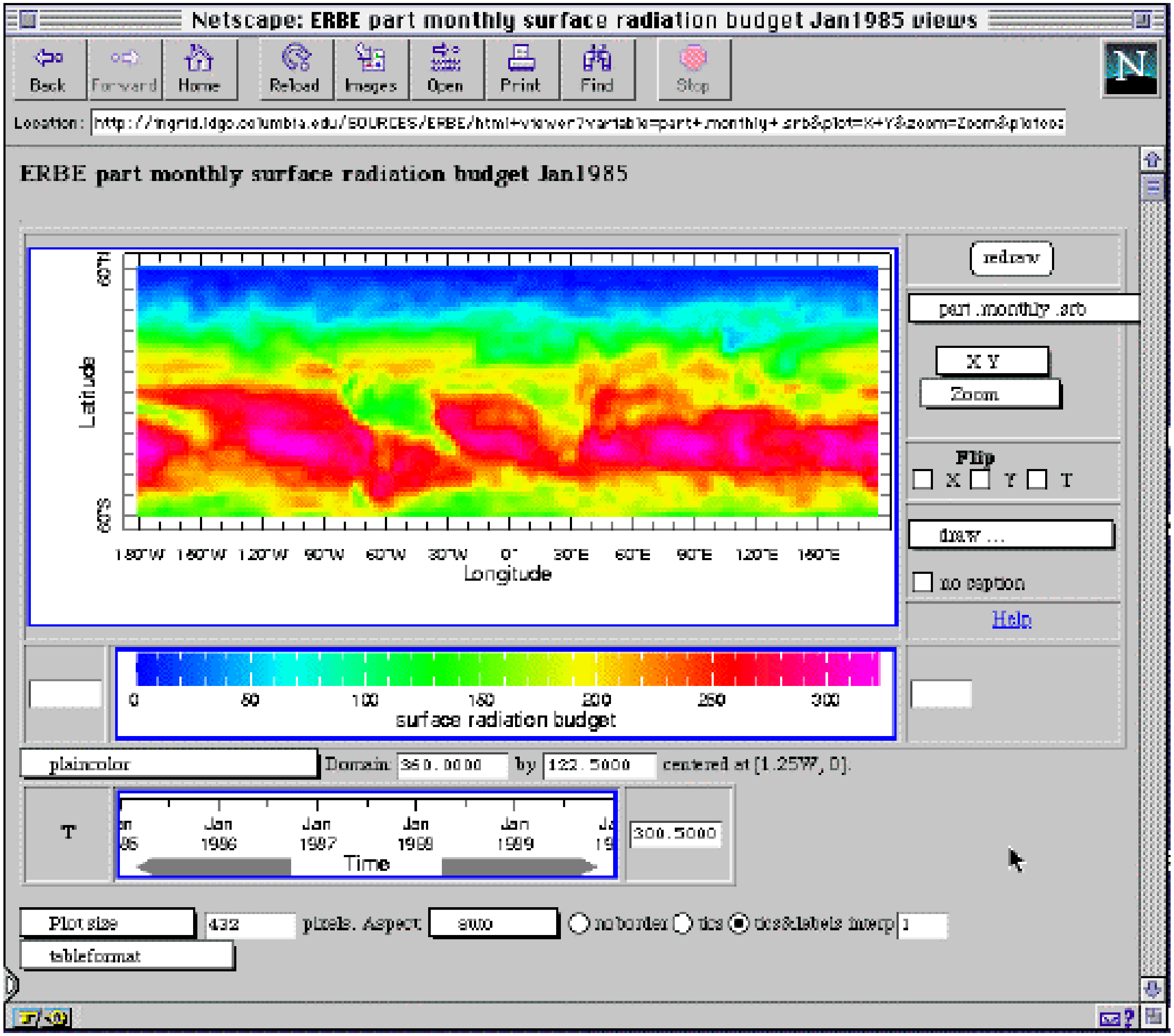

Figure 1. An interface for accessing and visualizing remote sensing data created by the Lamont-Doherty Earth Observatory of Columbia University. (Used with permission from http://rainbow.ldeo.columbia.edu/datacatalog.html)

All of these reasons support an important goal of current science education reform, which is to bring the process of learning science more in line with the actual practice of science. This goalóto give students a better understanding of what science is about by allowing them to *do* science instead of *memorize* scienceóis a central element of the science education standards that have been produced by organizations such as American Association for the Advancement of Science (AAAS) and the National Academy of Sciences. The distinction between memorizing science and doing science is an important one for digital libraries, because it is easy to view digital libraries narrowly as information sources. Even without access to the Internet, the challenge of teaching science in our schools is not that students do not have enough access to information. The challenge is that students do not have enough opportunities to engage in scientific inquiry. Digital libraries can contribute very little to science education if they are viewed simply as another source of information for students. They can make a significant contribution if they are viewed as resources that provide new opportunities for students to engage in science.

Availability vs. Accessibility

Because many of the efforts to provide digital libraries for learners are built around existing digital libraries for scientists or other experts, we must ask a second question. *Can we leverage the efforts expended in constructing digital libraries for experts in order to provide valuable digital libraries for learners? And if so, how?* As a first step toward answering that question, it can be instructive to consider simply making scientists' digital libraries available "as is" to teachers and learners.

When thinking about this approach, one of the authors was reminded of a research paper that he wrote for a science class when he was in junior high school. The assignment was to study some aspect of the pulmonary system and for some reason he became intrigued by hiccups. However, he wasn't able to find any satisfactory information at either his school or local public libraries. As it happens, he grew up a few miles from the National Library of Medicine in Bethesda, MD and convinced his parents to take him there one evening. Amazingly, he had full access to the library's resources and was soon searching through indices and requesting books journals from the stacks. However, as the pile of resources on hiccups accumulated in his carrel, he was confronted with the fact that he was unable to make sense of their contents. While the full resources of the National Library of Medicine were *available,* to him they were *inaccessible.* The problem with simply handing experts' digital libraries to learners is that the resulting resources will be available but not accessible.

Acknowledging the important distinction between availability and accessibility need not lead to despair over the value of scientists' digital libraries for learners, but it does lead to a recognition that these resources must be adapted to suit the needs and abilities of learners. Understanding the ways in which these resources should be adapted for learners is an important topic for research. Most current digital library research is about availability because availability of resources is the primary issue for expert users. Atmospheric scientists, for example, have the motivation and the know-how to take advantage of remote-sensing data if they can only get it when they need it. Members of the education community may lack both the experts' motivations and know-how. The challenges of availability are those that we most closely associate with current digital libraries research: digitization, storage capacity, indexing, search, retrieval, and transmission. Research on availability is primarily about technology. Research on accessibility is primarily about users. The challenge of this research is understanding the needs and abilities of educational users well enough to adapt digital libraries to them. In order to make digital libraries into valuable educational resources, we must focus our research efforts on the challenges of accessibility for learners.

Accessibility: A Digital Libraries Research Question

The question posed by the gap between availability and accessibility is, *how can we close the gap between the user and the digital library resources?* This gap is bracketed on one side by the significant features of the resources -- their specific uses and the prerequisite understanding necessary to take advantage of them -- and on the other side by the characteristics of the users -- their motivations, goals, activities, and background knowledge. One way to approach this gap is through an examination of the differences between the expert users of digital libraries and learners. These differences can be broadly characterized in the following ways:

	Experts	Learners
Motivation	Create new knowledge or create new instrumental techniques	Academic achievement and curiosity about the world.
Goals	Expressed in terms of tools and resources	Expressed in terms of tasks or knowledge
Activities	Structured by research community and funding sources	Structured by school assignments and personal interests
Background knowledge	Mastery of fundamental principles and significant experience in practice	Sketchy knowledge of elementary science

As an example, consider the differences between a climatologist and a high school senior that are both interested in the global warming controversy. The climatologist might ask the question, "What would be the effect of a 100ppmv increase on CO2 on the earth's net energy balance?" The high school senior might ask, "Is global warming going to happen?" The difference between the questions is not just one of specificity, but of goals, motivation, and background knowledge. The scientist's question is posed in terms of scientific processes and refers to specific data that he or she might use to answer the question, i.e., CO2 levels and net energy balance. It is posed in the context of a deep understanding of climate processes and of a set of practical goals and motivations that reflect the scientist's position in a community of practice. The student's question is likely motivated by a combination of concern over the future of his or her world and a need to fulfill an academic requirement by conducting an investigation. The vague phrasing of the question implies that the student has little understanding of climate processes that would help him or her to focus an investigation, and it makes no reference to any resources that would help the student pursue the question.

Despite the profound differences between the scientists' and students' goals, motivations, and background knowledge, the same digital library resources could prove equally valuable to each of their investigations. The challenge is to bridge the student to a point where he or she understands the scientific processes well enough to recognize which resources to use and how to use them to pursue his or her question in a meaningful way. The goal, simply put, of the adaptation of expert resources for learners is:

Take resources that enable experts to extend their knowledge and turn them into resources that enable learners to develop some of the knowledge possessed by experts by performing personally meaningful tasks.

Accessibility through Bridging

The key to adapting digital libraries designed for experts is creating a *bridge* between the learners' goals, abilities, and knowledge, and the requirements for productive use of the digital resources. Since 1992, the CoVis and SSciVEE Projects at Northwestern University have been investigating the adaptation of scientists' data libraries and scientific visualization tools for learners [1]. As part of this research effort, we have developed a three-step process for adapting experts' resources for learners. The adaptation process begins with a study of scientists, the resources they use, and the activities they engage in. The goal of this step is to understand the tacit knowledge that experts bring to their tasks and the ways in which they use their resources. The second step is to re-design the resources to provide enough support for learners to engage in activities that are closely modeled on those of the experts. The resources are re-designed, in some cases, to convey the experts' tacit knowledge to learners, and, in others, to compensate for their lack of that knowledge. The third step in the adaptation process is to develop carefully constructed activities that capitalize on students' intrinsic motivations to introduce them to the capabilities of the resources.

The overall goal of this effort is to identify areas in which we can create bridges that enable learners to take advantage of experts' resources. As part of this process, we have identified four ways which to achieve this bridging: interface design, activities design, organization and selection of resources, and documentation . We call the visualization environments that we are designing to provide these bridges, *supportive scientific visualization environments* to emphasize the additional support that bridging can provide.

Bridging through Interface Design

A digital library contains two primary user-interfaces: one to the collection as a whole, which allows a user to select individual resources to access, and one to the individual resources that make up the library. In a traditional library, the first (or collections) interface is provided by the card catalog and the second (item interface) by physical books and other materials. Digital libraries research generally focuses on the interface to the collection as a whole, because that is an issue of availability. Some digital libraries for experts, for example the data library in Figure 1, provide an interface to individual resources. In their case, this interface is provided by a scientific visualization tool. In many cases, however, the interface to individual resources in a digital library consists of a file transfer program that allows users to download resources to their local computers. Viewing and manipulating the resources is left to the responsibility of the expert.

In constructing a library for accessibility, attention to both interfaces is essential. In the story of our frustrated hiccup researcher at the National Library of Medicine, the obstacle to accessibility was not the card catalog, though it could have been if the protagonist was unable to translate his familiar term *hiccup* into the corresponding terms used by medical indices. The obstacle was the inaccessibility of the resources themselves. In our research, we have been exploring ways to construct supportive interfaces for both accessing and using resources. The goal of a supportive interface for accessing data is to help the learner to understand what data is available and what its uses might be. The goal of a supportive interface for viewing and manipulating data is to make it clear what the user is seeing and what operations can be meaningfully performed.

Our approach to building supportive user interfaces is to attempt to explicitly encode the tacit knowledge that experts bring to their use of digital resources. The goal of this interface design process is to take the tacit knowledge of experts and make it apparent in the user interface so that learners in a way that learners can use it. In our research efforts, we have taken as a starting point the sort of data libraries that NASA maintains for remote sensing data in combination with the sort of powerful, general-purpose scientific visualization environment that many scientists use in the course of their daily work.

Access to data. In contrast to an expert who approaches a library of resources with a knowledge of what resources are contained in the library and what their uses are, a learner approaches a library with the need to gather that knowledge. A supportive interface to data attempts to provide that information to the user. For example, Figure 2 shows a user-interface we have developed for data sets related to the earth's energy balance. This supportive interface contrasts with interfaces to data used by scientists that typically provide either an unannotated list of technical scientific terms, a list of file names, or a keyword search mechanism that requires that the user already know the name of the data that he or she is interested in. In this case, the interface to the data doubles as an instructive diagram that illustrates the relationship of the available variables to each other. Further, it enables the user to see a short description of each variable by passing the mouse over it's name on the diagram.

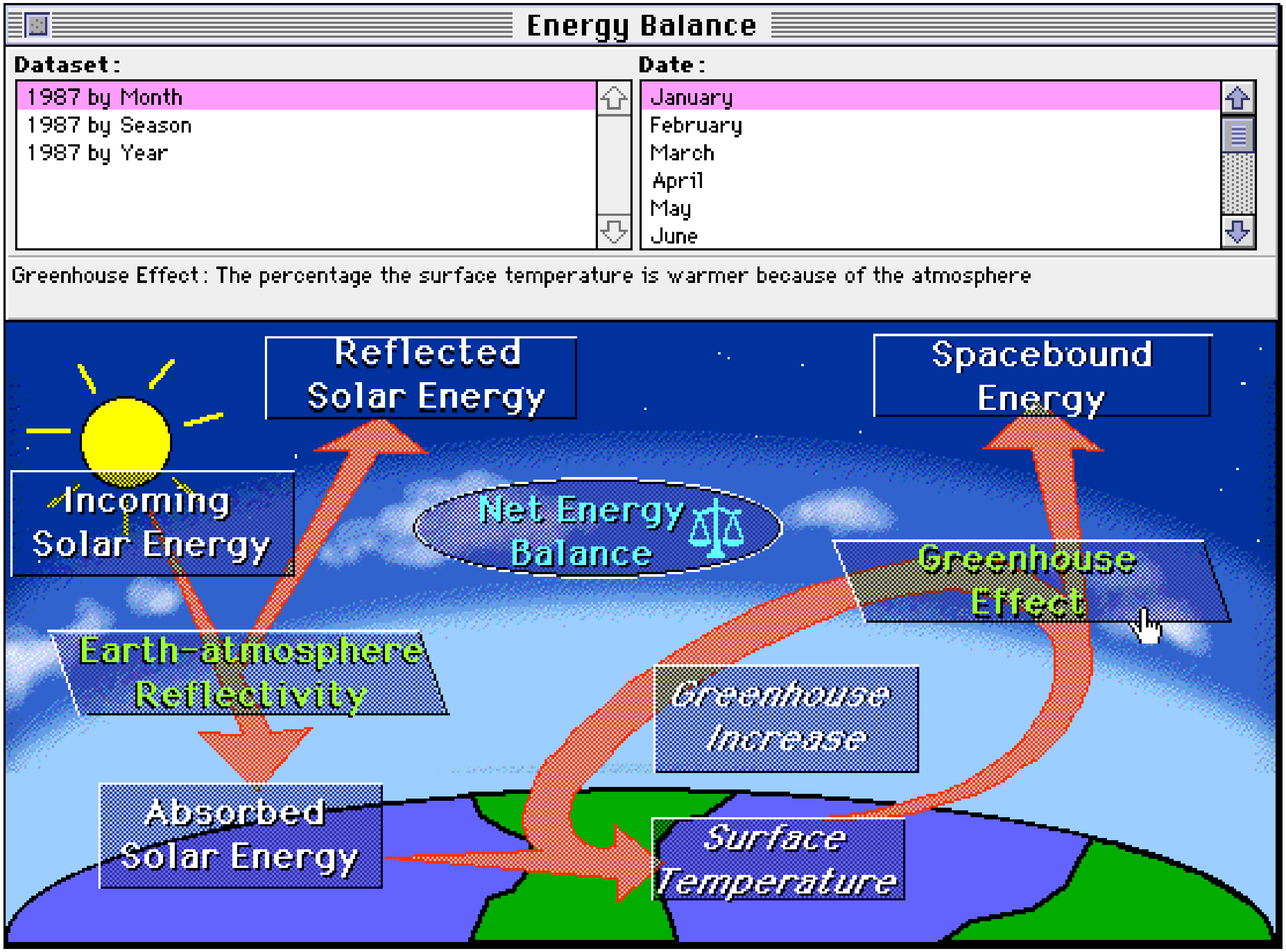

Figure 2. The interface for accessing earth energy balance data in the ClimateWatcher supportive scientific visualization environment.

Viewing and manipulating data. A supportive interface for viewing and manipulating data must communicate to the learner, at a level that he or she can understand, what it is they are seeing and what operations they can perform. Figure 3 shows a screenshot from Transform, [2] a popular and extremely powerful and 2-dimensional visualization environment used by researchers in a wide variety of scientific disciplines. To a non-expert, the visualization is almost completely uninterpretable. The variable being displayed is encoded in the filename that serves as the title for both windows. A careful reading of the ìtsea_level_1_0_88_0zî that appears in the title bar reveals to a climatologist who is familiar with this data that he or she is viewing the average midnight Greenwich Mean Time sea level temperature for January 1988. The geographic extent of the displayed region is not identified, and the numbers that appear in the window at the side have no units nor any indication of how their values map into colors in the visualization. As lacking in contextual markings as this interface is, expert researchers have no difficulty working with data and visualizations in this form because of the extensive tacit knowledge that they bring to the use of the data and tools.

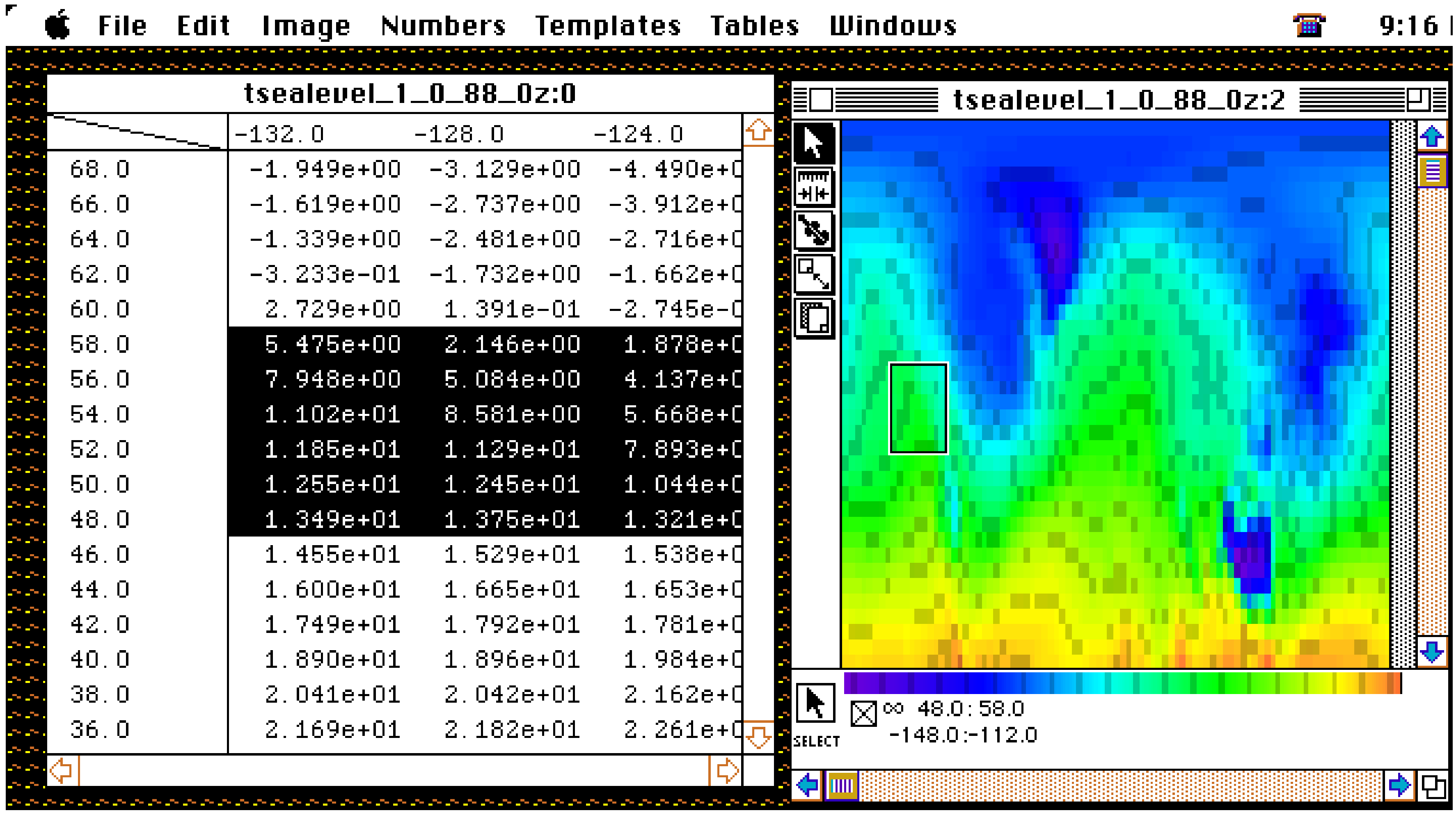

Figure 3. A visualization of surface temperature data for the Northern Hemisphere using the Transform visualization environment.

In contrast to the interface used by scientists displayed in Figure 3, the supportive scientific visualization environments we have constructed provide the learner with contextual information about geography (through latitude and longitude markings, as well as continent overlays), about units (through labels), and about the mapping of numerical values to colors (through a color palette display) [3] . Figure 4 shows a visualization window from ClimateWatcher.

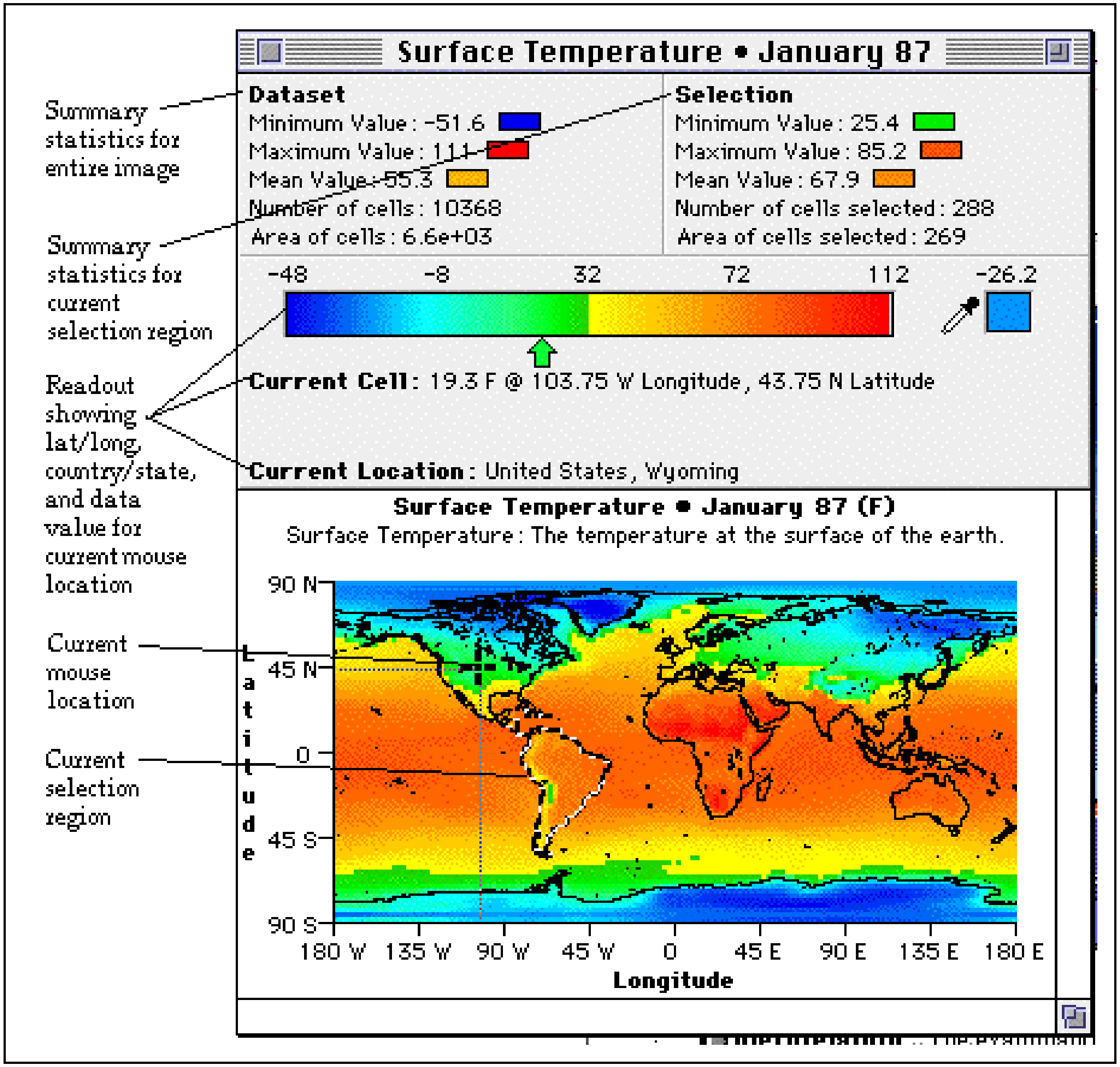

Figure 4. A visualization window from the ClimateWatcher program displaying contextual information .

Bridging through Resource Selection and Organization

The selection and organization of data or other digital libraries resources for expert users is driven directly by the goals of the users. The need to bridge to learners places additional requirements on the selection and organization of digital resources. For example, data archives used by scientists are typically organized by source and by variable. NASA's remote-sensing data archives are typically accessed by specifying a particular source, such as the GOES or TIROS spacecraft, or by specifying a parameter of interest, such as total column ozone. This organization of data is effective because the scientist users know how to translate their research questions into specifications for the data they need. However, learners may not know how to translate their questions into requests for data. One solution to this problem is to provide a bridge for learners by organizing data around questions, such as potential causes of global warming, implications of global warming, and evidence of historical global climate change. Organizing data or other digital resources around questions and themes that are meaningful to learners can provide a bridge that will enable them to locate resources that are appropriate to their needs.

Resource *selection* can also provide a bridge for learners. There are two challenges to accessibility that can be eased through resource selection. They are learners' lack of familiarity with the resources and their inability to relate the available resources to issues that interest them. One solution to this problem is to supplement the core resources with additional resources that can serve as a bridge to the experiences and interests of learners. For example, the global climate change data sets that we have focused on in our visualization environments consist primarily of data that record the radiative transfer of energy between the sun, the earth, the earth's atmosphere, and space. While researchers recognize the centrality of this data to the investigation of global climate change, learners find the variables represented to be unfamiliar, abstract, and uncompelling in the absence of a deep understanding of the relevant scientific processes. Through selection of additional data, we have succeeded in constructing a bridge for learners to prepare them for the use of this data.

As part of this effort, we have identified two classes of data that can serve as effective bridges to learners: data that represent familiar quantities and data that represent human causes and implications. For example, we have supplemented the abstract, unfamiliar variables with others that represent more familiar, concrete variables, such as precipitation, ground cover, and elevation above sea-level. These data provide a bridge for students by allowing them to work initially with quantities that they can reason about comfortably because of their experience with them in the real world, and then move on to data that represents less familiar, less concrete quantities. In addition, we have found that students have great intrinsic interest in variables that relate to human activities. In order to bridge to the energy balance data sets, we have included human activity data sets that provide a lead-in and motivation to focus on the energy balance data. These data sets represent quantities that enable learners to examine the possible human causes and implications of global warming. They include population density, political geography, and carbon emission into the atmosphere. Working with these human geography data sets helps draw learners into the issues that they can pursue further by moving on to the data sets representing the core scientific issues.

Bridging through Activity Design

One doesn't ordinarily associate activity design with the design of digital libraries because digital libraries for experts are designed to support the pre-existing activity structures of their expert users. However, for learners who are unfamiliar with the goal and activity structures of experts, an effective strategy for increasing the accessibility of digital library resources can be the design of bridging activities. These activities should help learners to understand the appropriate uses of the available resources and to show users how their goals can be served through uses of these data. The design of these bridging activities requires a careful analysis of the goals, motivations, and experiences of learners in order to develop activities that seem natural to learners at the same time that they help them progress along the desired developmental sequence. A successful design for a bridging activity should present an opportunity for learners to engage in practices that are familiar and fit their natural motivations at the same time that it introduces them to the new practices and goals that correspond to expert use of the digital resources. Therefore, it requires an artful blending of learner-centered and expert-inspired design.

In our work, we have developed a set of bridging activities that center around the use of scientific visualization as an expressive medium. Included in the design of ClimateWatcher are a set of paint tools modeled on the tools in popular graphics programs that enable users to create their own data by "painting" data values on a color map. The drawing activity capitalizes on the familiar experiences of learners to introduce them to scientific visualization as a representational medium. In a variety of different activities that we have created, learners paint visualizations to express the state of their understanding, to invent novel worlds, and to represent hypothetical scenarios of climate change. In one activity sequence we have designed for learners, they are introduced to color maps as a representational medium through an exercise in which they attempt to construct a scientific visualization without using any references. Using a combination of memory and inference, students paint a color map of a familiar variable, such as temperature, population, or surface elevation. Their creations then serve as a vehicle for learning about the techniques of scientific visualization as they use the features of ClimateWatcher to compare their hand-drawn visualizations with measured data both visually and mathematically. In another set of activities, learners invent entire worlds by creating visualizations of them, and use investigations of the climate data for the earth to construct a climate for their own worlds. Figure 5 shows an elevation map and the accompanying temperature map for a world invented by three high school students.

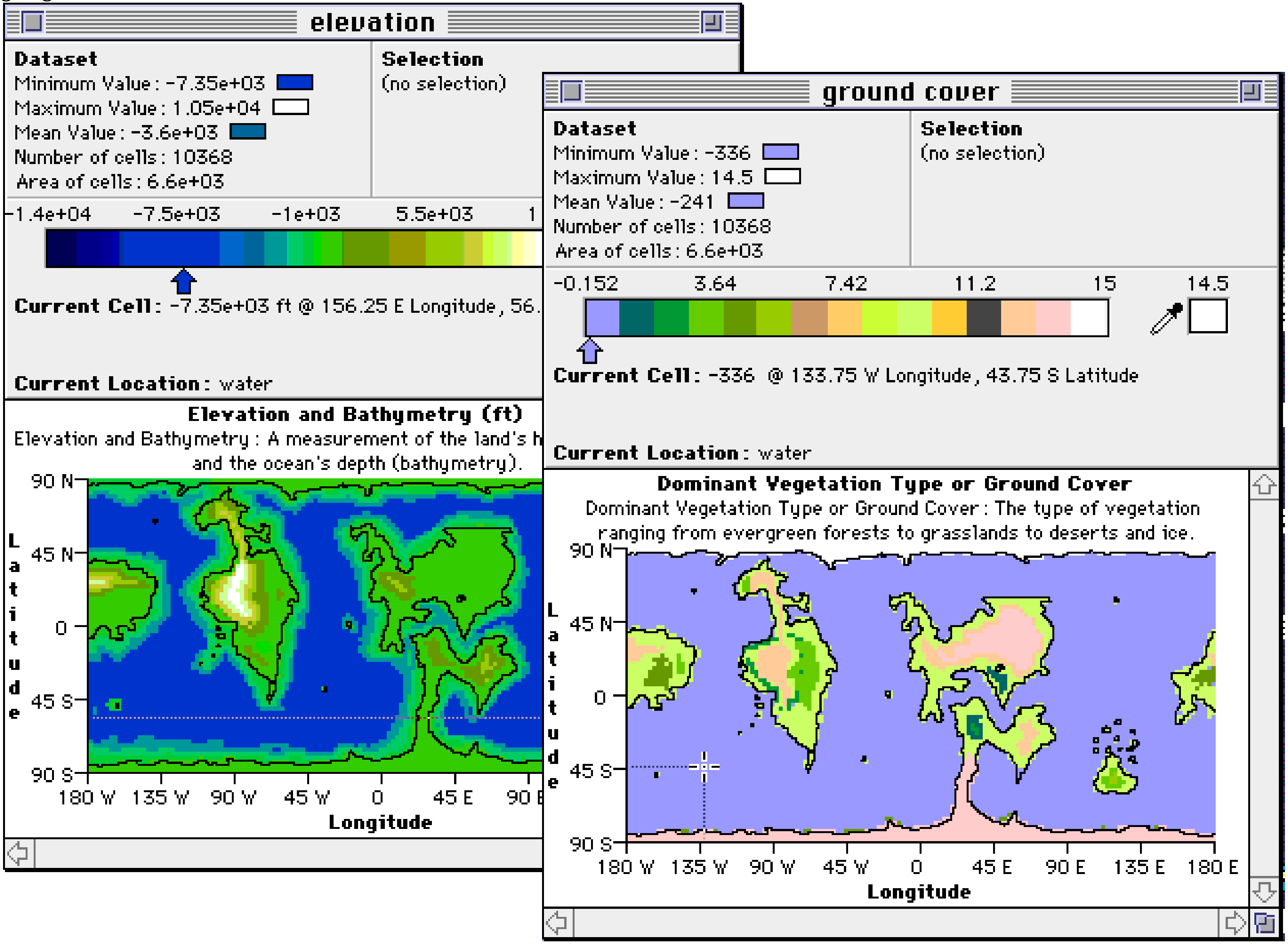

Figure 5. Visualizations for surface elevation and temperature for a world invented by high school students whose climate is modeled on the earth's climate.

These learner-inspired drawing activities provide an introduction to the techniques and resources supported by the library of digital data. They allow students to engage in familiar activities and pursue goals that are meaningful to them, but they also help students to develop new understanding of the value of available digital resources and learn expert practices for the use of the resources.

Bridging with Documentation

Documentation can be an important contributor to accessibility. However, as anyone who has created documentation and discovered that users ignore it can attest, it is not a magic bullet. As one might expect, documentation designed for learners has important differences from documentation designed for experts. An expert's need for documentation of digital resources typically involves information about sources and reliability. Learners, on the other hand, require documentation that will help them to understand what the resources are and how they may be used to resolve questions of interest. Once again the challenge is taking knowledge that an expert brings to the resources and making this knowledge a part of the resources in a way that enables the learner to acquire this knowledge through his or her interactions with the digital library. The documentation that we are constructing to accompany the global warming data sets in our supportive environments will include explanatory information about: radiative heat transfer, sources and meanings of available data, and prior examples of ways in which that data has been used.

These forms of documentation go well beyond the documentation that accompanies most data libraries, but it provides a scaffold to support learners as they learn to take advantage of the available resources. Once they understand the meaning and uses of the resources, learners will be prepared to take advantage of the forms of documentation that experts require that enable them to make informed judgments about the reliability of the conclusions they are able to make from their use of the resources.

Conclusion

The value of digital libraries is in the authentic activities that they can allow learners to engage in. It is clear that digital libraries developed for experts can be valuable educational assets. However, to capitalize on their potential, these digital libraries need to be made accessible for learners through a variety of *bridging strategies*. Each of the bridging strategies presented here: supportive interfaces, activities design, resource selection and organization, and documentation is designed to provide learners with enough of the hidden context and knowledge that experts bring to their tasks to enable students to use the digital resources as learning resources. These bridges require additional effort above and beyond the construction of experts' digital libraries, but they take the form of value-added support that leverages the initial investment. The addition of these bridges can transform these resources into invaluable resources for education, and can make digital libraries a common ground that provides a meaningful link between scientific researchers or other expert practitioners and the educational community. Creating such a common ground will increase the likelihood that the graduates of our educational system will be prepared to make sound decisions informed by results from the scientific community.

Acknowledgements

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Notes

[1] The Learning Through Collaborative Visualization (CoVis) Project is a national networking testbed investigating the use of advanced computing and communications technologies to support project-based science education in secondary schools. The Supportive Scientific Visualization Environments for Education (SSciVEE) Project is investigating the design of scientific visualization environments for learners. Information on these projects is available on the web at http://www.covis.nwu.edu/ and http://www.covis.nwu.edu/sciviz/sciviz.html.

[2] Formerly distributed by Spyglass, Inc., Transform is now available from Fortner Research.

[3] It is important to note the difference between the tasks that researchers perform with scientific visualization tools in the course of their research activities and those that they perform in order to prepare results for publication or other communicative acts. Many of the additional elements that researchers add to scientific visualizations to support communication with others are the same elements that we have found are necessary in the user interface of working environments for learners.

Revised September 17, 1996 by the Editor with instructions from the Authors. In the earlier version, Figures 2 and 3 had inadvertently been transposed, and footnotes have been added. We apologize for any misunderstandings that may have arisen.

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