

DATA VISUALIZATION TOOLS FOR SCIENCE AND MATH

B. KOLVOORD

James Madison University, Harrisonburg, VA 22807

kolvoora@jmu.edu

As the computers available in schools become more powerful, more and more exciting tools are available to science and math students and teachers. Visualization tools, such as image processing, geographic information systems, modeling, and simulation software, are a class of tools with particular promise. These tools are being used in schools across the country to integrate computer use with the curriculum and to bring more hands-on inquiry to the students. A primary goal of using these computer-based tools is to aid students in developing a deeper understanding of the science and math (not the computers) and to help make difficult concepts a little easier to grasp (and visualize).

In particular, these tools allow students to collect, analyze, and manipulate data, a fundamental requirement of the Virginia Standards of Learning [1]. More importantly, these tools allow students with a variety of different learning styles, especially visual learners, to help make abstract concepts into concrete expressions. Teachers can use the computers as a laboratory to study phenomena they could never fit into their classroom (like remote sensing of Earth to study land use and geology from space).

One of the challenges in bringing these tools to students is how to do the faculty development to bring the tools to teachers. In this session, we'll explore the possibilities that these tools offer, examine the challenges, and try to understand how to prepare future teachers to use these and other tools in their classrooms.

There are two complementary forces at work in the use of educational technology in K-12 classes. There is a push from groups that advocate the use of computers integrated with instruction. Many districts have made substantial investments in hardware and networks only to find the machines being used as little more than glorified typewriters. There is pressure to find ways to make use of the computers as an integral part of the learning process rather than as an add-on. There is also a pull from the curriculum and from content groups that focus on the opportunities that computers offer to bring new learning opportunities and to address students with different learning modalities. The pace of change in science content has drastically changed the make-up of current secondary science classes (compare a current high school biology class to what was offered a generation ago) and introduced opportunities for curricular content that can most easily be facilitated with computers. We highlight some of the curriculum connections below in Table 1.

Visualization Tool	Subject Area	Grade Level	Content Connection/Description
Image Processing	Biology	9-10	Mitosis: Microscopic movie of a cell undergoing mitosis. Students discern the different stages and develop a model for the process.
Image Processing	Earth Science	9-12	Global Climate: Time-lapse sequence of the Antarctic ice pack. Students measure the size of the ice pack as a function of month and year and compare measurements.
Image Processing	Physics	10-12	2-D Motion: Movie of a person shooting a free throw. Students measure the motion of the ball and use the trajectory to calculate g .
Image Processing	Biology	7-8	Homologous Structures: Images of x-rays of different animal forelimbs. Students identify the animal and compare and contrast structure.
GIS	Earth Science	9-10	Natural Resources: Students map the location of different natural resources and identify their geologic origins.
GIS	Earth Science	10-12	Plate Tectonics: Mapping of earthquakes and volcanoes. Students explore the location of volcanoes and earthquakes and compare their location to plate boundaries.
GIS	Ecology	10-12	Population Dynamics: Students map the location and growth rates of humans and other species and compare with available resources.
Molecular Modeling	Chemistry	11-12	Molecular Structure: Students explore the three-dimensional structure of molecules and the implications for chemical bonding.
Molecular Modeling	Biology	10-12	Amino Acid Structure: Students build models of amino acids and study protein structure and function.
Simulation	Biology	9-10	Epidemiology: Simulation of the mechanisms of disease spreading. Students develop simulations of the spread of a disease as a function of different parameters.
Simulation	Chemistry	11-12	Rate Equations: Simulation of reaction rates in simple systems. Students model chemical kinetics and observe the change brought about by changing rate constants.

Table 1. Examples of Curricular Connections for Various Visualization Tools

Visualization tools allow access to science content for a variety of students for whom traditional methods of teaching are inadequate. The connection for visual learners is a clear and consistent theme of the projects to date [2, 3, 4]. If we want to have broader participation in science by all students, we need to find ways to reach out to those who have not been well served in the past. Visualization tools offer one avenue of access for these students.

These tools enable a strong constructivist focus in the math and science classroom [5]. They are also available (for the most part) on both Macintosh and PC platforms, eliminating some of the prior focus on the platform and allowing teachers and students to concentrate on effective ways of using these tools in their subject areas.

In order to have a common context, we need to define what we mean by scientific visualization and list reasons and examples for its curriculum “pull” into the classroom. Scientific visualization involves the use of computers to generate representations of large and complex data sets as images. The images can be static or animated and they can represent a range of phenomena from the atomic to the astronomical. Specific examples include MRI imaging in medicine, a wide array of electron microscopy technique for imaging at resolutions to the atomic level, and software to portray the results of large-scale climate models, to name just a few. Figure 1 shows some additional examples with applications to earth science, physics, chemistry, and biology. Table 1 lists specific curriculum connections. The technology is not new, but the increasing power of available computers increases the rich array of subjects that can derive benefit from this technique. The use of scientific visualization is widespread across the scientific community as it is now possible to take abstract concepts and make them concrete. Scientists have made extensive use of this technique and educators are coming to appreciate its value [2]. The challenge is how to successfully move it from research laboratory to classroom.

Scientific visualization does not mean “cutting-edge” only. For any technology to take root in the classroom, it must support current curriculum (see Figure 1 and Table 1) and standards (e.g. the Virginia Standards of Learning [1]). Visualization tools do this very nicely, from dissecting a microscopic animation of mitosis, to looking at earthquakes and faults in North America with a GIS program, to analyzing the physics of a free throw. Table 1 shows just a few examples of specific curriculum applications for each tool. These tools

support the kind of active inquiry and constructivist learning demanded by all the national standards and state frameworks [1, 6, 7, 8].

Gordin and Pea [3] list the following ways in which scientific visualization can impact education:

1. Make a scientific view of the world more accessible.
2. Provide a means for authentic scientific inquiry.
3. Empower students with tools they can use in a wide variety of fields.
4. Lay groundwork to enable students to understand and critique scientific policy.

Each of these methodologies connects strongly with the National Standards in both science and math and reinforces the reforms that have been building over the past few years. They also help address a variety of learning styles opening the doors of math and science to a more diverse population. Teachers are actively looking to improve their practice and scientific visualization offers a way to integrate computers and reform.

A variety of projects have pursued the exploration of how specific visualization tools can impact student learning [4, 9]. Among these are image processing and analysis projects including the Image Processing for Teaching project at the University of Arizona [2], the Co-Vis project at Northwestern University [3], the work of Tanimoto at U. Washington, the simulation-based work of the CC-Stadus/Sustain projects (*Stella*-simulation software) based in Portland, OR, and others. Geographic Information Systems are another class of powerful tools that are starting to find their way into pre-college curricula. The NASA-CCITT project at Prince George's Community College is a good example of this type of work. Each of these projects have used visualization-based software to motivate students of all abilities to the study and deeper understanding of science and math. As Tinker [10] points out, for middle grades "the concentration on modeling, particularly dynamic modeling, will provide a key underpinning for a range of scientific theorizing..." Each project reports success in attracting a broad cross-section of students and taking advantage of their inclination toward visual learning, and each project has a strong teacher development and outreach function.

The different approaches of these projects have led to similar conclusions: visualization tools can enhance the learning and achievement of students in math and science, especially women and students of color (cf. Raphael and Greenberg [11, 12] and Curriculum Technology

Quarterly [13]). These tools can also help to bridge the transition for teachers as they try to incorporate authentic discovery- and inquiry-based learning while still maintaining the content necessary to meet the content standards evolving both nationally and in many states.

In this context, visualization includes working with both real data and simulations. Thus, it includes image processing and analysis, molecular modeling, modeling and simulation, and geographic information systems. There are a variety of different pieces of software for these applications; however, there are many commonalities. Furthermore, visualization tools offer ways to access the myriad of data on the World Wide Web that go beyond the fairly mundane information gathering that makes up much of education's use of the Web. These tools can turn the Web into a laboratory for exploration and discovery.

The critical missing piece in developing the use of these tools is the professional development for both in-service and pre-service teachers. All of the projects mentioned above have had staff development as a central and ongoing feature. However, most of the staff development has gone to in-service teachers, leaving pre-service teachers woefully underserved. Our challenge is to work with collegiate faculty in both education and the content disciplines to integrate these tools in their teaching. There is precious little time to add additional course requirement, yet there is a strong need on the part of aspiring math and science teachers to add these tools to their arsenal (they can also serve to seed interest and training in the schools in which they eventually work). Having college faculty integrate these tools and model that sort of teaching in the methods and content classes will make major strides in bringing the pre-service teachers to a deeper understanding of the value and use of the computers in the math and science classroom. ■

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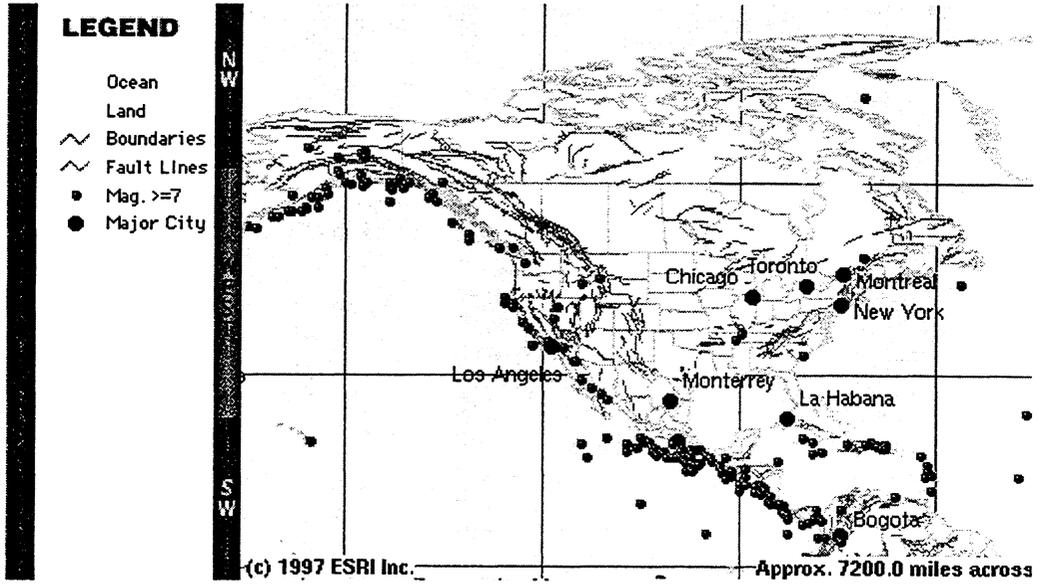


Figure 1a. A GIS map of earthquake sites and fault lines in North America. Data courtesy of ESRI, Inc.

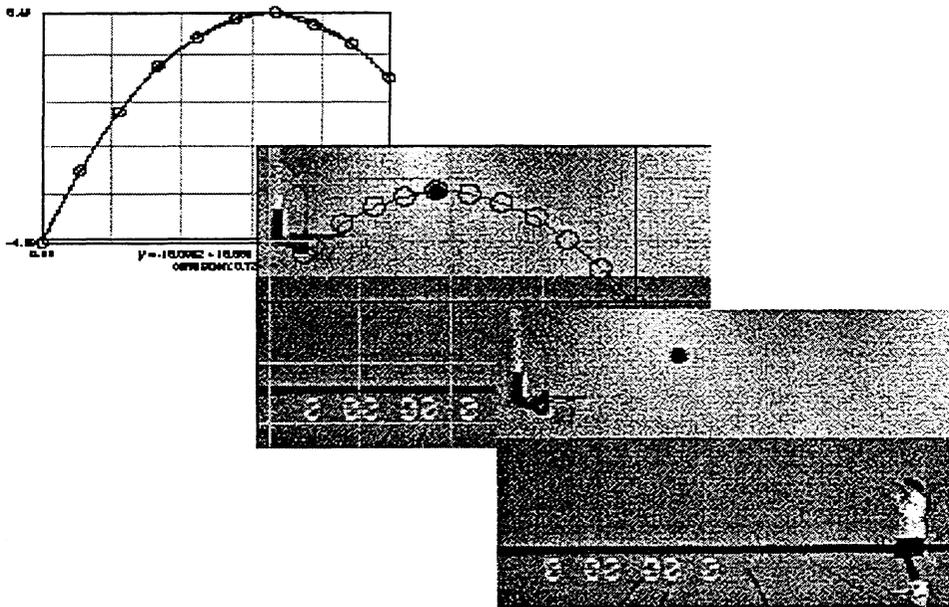


Figure 1b. Trajectory of a free throw. (Image © University of Arizona Board of Regents).

