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Preparing Tomorrow's Science Teachers to Use Technology: Guidelines for Science Educators

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Science and technology education have enjoyed a meaningful partnership across most of this century. The work of scientists embraces an array of technologies, and major accomplishments in science are often accompanied by sophisticated applications of technology. As a result, a complete science education has, in principle, involved a commitment to the inclusion of technology, both as a tool for learning science content and processes and as a topic of instruction in itself (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). These elements have traditionally been a part of teacher education in secondary science.

Science education has generally involved teaching not only a body of knowledge but also the processes and activities of scientific work. This view has linked the scientific uses of technology with hands-on experiences. The term "hands-on science" was descriptive of the major curriculum reform projects of the 1960s and became a label for a revolution in teaching science through the next two decades (Flick, 1993). So-called "hands-on science" instruction impacted teacher education as new curricula made its way into preservice courses. Teacher education was also influenced by teaching methods, such as the learning cycle (Lawson, Abraham, & Renner, 1989), based on theories of student learning that implied the necessity of interacting with physical materials.

The explosion of digital technology has created a revolution similar to the "hands-on" movement of the 1960s. The flexibility, speed, and storage capacity of contemporary desktop computers is causing science educators to redefine the meaning of hands-on experience and rethink the traditional process of teaching. The challenge facing both science educators and science teacher educators is to evaluate relevant applications for information technologies in the science curriculum. At the same time, instruction utilizing information technologies must reflect what is known about the effectiveness of student-centered teaching and learning.

The impact of digital technologies on science teacher education is more pervasive than any curricular or instructional innovation in the past. The impact can be felt on three fronts. First, as with the hands-on science movement, digital technologies are changing the ways teachers interact with students in the classroom. Psychological theories (Borich & Tombari, 1997) based on the importance of language to learning, the ways organizing and relating information facilitates understanding, and the influence of social factors in the classroom are all impacted by digital technologies. Second, teacher education courses are not only influenced by new K-12 curricula, they are also influenced by instructional approaches, fueled by the National Science Education Standards (NRC, 1996), that incorporate a variety of digital technologies. Technological applications go beyond K-12 curriculum to the delivery of college level content. For instance, faculty and students explore web resources for educational statistics or education-related reports and course resources.

Both of the major national reform documents are on the web (AAAS, 1993, at http://www.project2061.org// and NRC, 1996, at http://www.nap.edu/catalog/4962.html). Third, faculty and students alike are interacting in new ways afforded by digital technologies. Faculty and students have virtual discussions related to course content, advice, and counseling in a wide variety of times and places through via email, cell phones, pagers, and features of the web. Faculty and students now produce documents with more information and in far more diverse formats as a result of desktop publishing, online libraries and databases, and file transfer capabilities. The pervasiveness of digital technologies motivates a thorough review of technological impacts on curriculum and instruction in science teacher education.

The following technology guidelines for science education are intended to provide assistance in designing instruction and to guide applications of technology to support science teacher education reform, as framed by *Benchmarks for Scientific Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996). The Association for the Education of Teachers in Science (AETS) joins other national associations of teacher educators in mathematics, English, and social studies through the National Technology Leadership Initiative to guide thoughtful consideration for how best to use contemporary technologies to enhance subject-matter focused educational goals in the preparation of teachers.

Proposed Guidelines for Using Technology in the Preparation of Science Teachers

1. Technology should be introduced in the context of science content.

2. Technology should address worthwhile science with appropriate pedagogy.

3. Technology instruction in science should take advantage of the unique features of technology.

4. Technology should make scientific views more accessible.

5. Technology instruction should develop students' understanding of the relationship between technology and science.

1. Technology should be introduced in the context of science content.

The first principle is centered on the notion that technology should not be taught merely for its own sake in the preparation of science teachers. Features of technology should be introduced and illustrated in the context of meaningful science. In other words, technology should be presented as a means, not an end. This principle has implications for teaching science content, as well as for science teacher preparation. For example, preservice teachers in science education programs are often required to take a generic educational technology course taught by an instructional technology expert. In this class, the preservice teachers are supposed to develop a variety of technology-related skills, including the ability to use word processors, presentation software, spreadsheets, and the Internet. Preservice teachers typically are then left to apply their newly developed technology skills to teaching content in their subject area.

This approach is backwards. Teaching a set of technology or software-based skills and then trying to find scientific topics for which they might be useful obscures the purpose of learning and using technology in the science classroom—to enhance the learning of science. Furthermore, this approach can make science appear to be an afterthought. Preservice teachers are, in essence, left to develop contrived activities that integrate a set of decontextualized instructional technology skills into the context of their classroom.

If the purpose of technology in science teaching is to enhance science teaching and learning (rather than for the technology's sake alone), a different approach is necessary. For example, teacher educators at Oregon State University and the University of Virginia are collaborating on a project designed to teach Internet and spreadsheet skills to preservice science and mathematics teachers in the context of an exploration of the El Niño weather phenomenon. Considering its impact on local weather and climate, El Niño holds both interest and relevance to the average student. Certainly, it has provided meteorologists and climatologists with a powerful framework for interpreting and predicting weather patterns.

Recent media coverage of the impacts of El Niño has made it a familiar scientific topic for students of all ages. However, fact and fiction became confused in the public's eye as the media began blaming El Niño for all sorts of natural and social events. This hype resulted in a variety of misunderstandings about the phenomenon. Thus, while most students are familiar with the concept, few can confidently discuss its causes and impacts. Preservice teachers may be challenged, for example, to use Internet resources to locate accurate information concerning the causes and effects of El Niño (see Appendix A, "What Is El Niño?" Background Resources).

Such an activity supports the development of skills typically addressed in educational technology courses, including using the Internet to locate relevant information and discriminating between useful and non-useful information. It also sets the stage for discussion of the advantages and concerns of student use of the Internet. Where it differs from the traditional approach is that these lessons are situated in the context of learning science.

2. Technology should address worthwhile science with appropriate pedagogy.

Much has been learned about effective science instruction since the emergence of science education as a field in the 1950s. Teaching science for understanding, instead of for rote memorization, requires students to be active participants who are engaged in asking questions, observing and inferring, collecting and interpreting data, and drawing conclusions (AAAS, 1993; Bybee, 1997; Goodrum, 1987; Matthews, 1994; NRC, 1996; Tobin, Treagust, & Frasier, 1988). In essence, teacher education courses should emphasize methods for providing students with opportunities to *do* science, in addition to learning the facts and concepts of science.

Content-based activities using technology should be used in the process of modeling effective science teaching for new teachers. Thus, appropriate uses of technology should enhance the learning of worthwhile science concepts and process skills, as well as reflect the nature of science. This guideline and Guideline 1 are based on the same principle that science should be learned in a meaningful context. Additional work has been done related to this important guideline, and **Appendix B** contains a more extended review.

Furthermore, activities involving technology should make appropriate connections to student experiences and promote student-centered, inquiry-based learning. Activities should support sound scientific curricular goals and should not be developed merely because technology makes them possible. Indeed, the use of technology in science teaching should support and facilitate conceptual development, process skills, and habits of mind that make up scientific literacy, as described by the *National Science Education Standards* (NRC, 1996) and *Project 2061* (AAAS, 1993).

It is clear from the *Standards* (NRC, 1996) that "student inquiry in the science classroom encompasses a range of activities" (p. 33) that are scaffolded by the teacher. Teachers scaffold student engagement in inquiry by providing opportunities for, observing, collecting data, reflecting on their work, analyzing events or objects, collaborating with teacher and peers, formulating questions, devising procedures, deciding how to organize and represent data, and testing the reliability of knowledge they have generated.

Technological support for inquiry is not the implementation of one application but a bundle of applications (Germann & Sasse, 1997). Consequently, teacher education courses must make appropriate pedagogy visible through the complex interactions among students and classroom technologies. Technology can support student investigations and direct collection and presentation of data through real-time data collection via microcomputer based probeware. PowerPoint or spreadsheet functions support presentations that demonstrate the relationship between hypothesis and data. Further manipulations of the display can help students formulate conclusions based on data. For example, by examining various graphical formats, students can be guided to think about implications by looking for trends, identifying categories, or making comparisons. Through microteaching environments and supervised experience, new teachers should become aware of how applications of technology help students share and collaborate in building their knowledge of science and scientific inquiry.

The previously described El Niño project is an example of a project in a methods course for modeling the blending of worthwhile science with appropriate pedagogy. Searching the Web to locate information about the El Niño phenomenon is a typical way the Internet is used in K-12 and higher education classrooms. New teachers learn what science has to say about the concept of El Niño, as well as how to use the Internet to locate current information. However, if teaching stops here, teachers do not develop the appropriate pedagogy of scaffolding student participation in scientific inquiry. Without the follow-through to include inquiry, such an approach may be criticized for conveying the products of scientific investigation without due attention to the processes of how scientific knowledge is produced, and the tentative nature of the knowledge itself. As Schwab commented in 1962, science is too commonly taught as

> …a nearly unmitigated rhetoric of conclusions in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths (in which students are asked) to accept the tentative as certain, the doubtful as undoubted, by making no mention of reasons or evidence for what it asserts. (p. 24)

Such criticism, while commonly applied to traditional curricular materials, is just as appropriate to common usage of the Internet in schools today.

An extension of the El Niño activity that also incorporates inquiry would start with students asking questions (see Appendix C, El Niño Project). Most students are curious to know whether El Niño actually impacted local weather—one aspect of this project in which students also find relevancy. It turns out that historical and current weather data are available on the web, and students can use these data to support an answer to their question. They will not find the answer handed to them on a silver platter, however. Once they locate the data, they will find they need to organize and manipulate it so they can reach and support a conclusion.

Throughout this student-centered process, new teachers see science taught in a manner consistent with the way scientists do their work. They ask a scientific question and devise a method for answering the question. They collect and organize data. They reach conclusions based on that data, and they share their conclusions with their peers. Furthermore, by discussing the details of the data and the various approaches to analyzing the data, students have opportunities to consider the tentative nature of scientific knowledge.

While seeing science presented in an authentic context, new teachers also learn to use web-based databases, import and export data sets, use spreadsheets to calculate summary statistics and construct tables and graphs, and use word processing and/or presentation software. Thus a bundle of applications (Germann & Sasse, 1997) is learned in the context of appropriate inquiry-based science instruction.

Modeling the use of technologies in the context of learning science is critical in teacher education for another reason. A common maxim in teacher preparation is that "teachers teach the way they were taught." Experience has shown that few preservice teachers are able to make the intellectual leap between learning to use technology out of context in their teacher preparation programs and using it in the context of teaching science in the classroom. Teachers need to see specific examples of how technology can enhance science instruction in their content areas before they can hope to appropriately integrate technology in their own instruction.

3. Technology instruction in science should take advantage of the unique features of technology.

Technology modeled in science education courses should take advantage of the capabilities of technology and extend instruction beyond or significantly enhance what can be done without technology. New teachers should experience technology as a means of helping students explore topics in more depth and in more interactive ways. An evaluation study of the Technology-Enhanced Secondary Science Instruction (TESSI) project (Pedretti, Mayer-Smith, & Woodrow, 1998) documented the impact of technologies integrated at many levels. A preservice methods course could critically examine the content and outcomes of this study as a way of applying unique features of technology for learning science. For example, students in TESSI classrooms ran virtual labs and demonstrations using the technology to slow down the action and repeat complex activity. Students were able to rerun virtual force and motion demonstrations and follow how each step was represented on the screen in graphical form. Students in the methods course could discuss how well these examples utilize unique technological features.

Studies have clearly documented the value of technological capabilities for enhancing the presentation of complex or abstract content, such as computer visualization techniques (Baxter, 1995; Lewis, Stern, & Linn 1993). However, a concurrent concern is that novelty and sophistication of modern technologies might distract or even mislead students in understanding science concepts that are the target of instruction. Discussion in the methods class could continue with a critical look at technological applications to assess whether their capabilities supported or detracted from learning opportunities. An objective of the TESSI project was to document the roles and perspectives of learners, teachers, and researchers participating in the project (Pedretti et al., 1998). One hundred forty-four students were either interviewed or surveyed after completing one school year of physics or general science in the project. Classroom instruction involved student use of (a) simulations to extend understanding of physics concepts; (b) laser discs, video tape, and CDs; (c) real-time data collection and graphical analysis tools associated with computer-interfaced probes and sensors; (d) computer analysis of digitized video; (e) presentation software; and (f) interactive student assessment software. A goal of instructional design was to employ technology to enhance the teacher's role in the classroom, not to replace it.

Discussion of this study and others like it helps establish this central goal that should be used in the assessment of instructional design and implementation in teacher education courses.

None of the students interviewed felt that computer experiences should entirely replace the "doing" and "seeing" of actual laboratory or in-class demonstrations. They were clear in stating that computer technologies and hands-on lab experiences play a complementary role, so that the actual event under study, such as a wave propagating down a spring, can be perceived as a concrete event then analyzed by appropriate simulations. Cognizant of balancing technological enhancements with checks of student understanding, the teachers designed study guides that kept students mindful of instructional goals, integrated technology with teacher-direct instruction, and prompted student self-evaluation through small-group reviews and conferences with a teacher.

Another criteria for assessing instructional design tasks in methods courses is that taking advantage of technology does not mean using technology to teach the same scientific topics in fundamentally the same ways as they are taught without technology. Such applications belie the usefulness of technology. Students in the Pedretti et al. (1998) study took tests on computers. The software was able to score and give general feedback more quickly than a teacher-scored test. More sophisticated, experimental software is being designed to provide structured guidance as students analyze and interpret data (Cavalli-Sforze, Weiner, & Lesgold, 1994, http://advlearn.lrdc.pitt.edu/). Through an Argument Representation Environment, the prototype software helps students construct and propose theories and guides individuals or groups in designing is experimental software highlights another issue for science methods instructors: Different types of software will require different kinds of support for new teachers. For instance, course activities and discussion should guide new teacher understanding of the processes of coding and layering of data in ArcView in order to appreciate the scientific meaning in ArcView graphics (see http://www.esri.com/industries/k-12/k-12.html). In taking advantage of the real-time graphing capabilities using probeware and computers, researchers have found that college students preparing to be elementary teachers must be more carefully taught how to interpret graphs (Svec, Boone, & Olmer, 1995).

Using technology to perform tasks that are just as easily or even more effectively carried out without technology may actually be a hindrance to learning. Such uses of technology may convince teachers and administrators that preparing teachers to use technology is not worth the extra effort and expense when, in fact, the opposite may be true.

4. Technology should make scientific views more accessible.

Many scientifically accepted ideas are difficult for students to understand due to their complexity, abstract nature, and/or contrariness to common sense and experience. As Wolpert (1992) aptly commented,

> I would almost contend that if something fits in with common sense it almost certainly isn't science. The reason again, is that the way in which the universe works is not the way in which common sense works: the two are not congruent. (p.11)

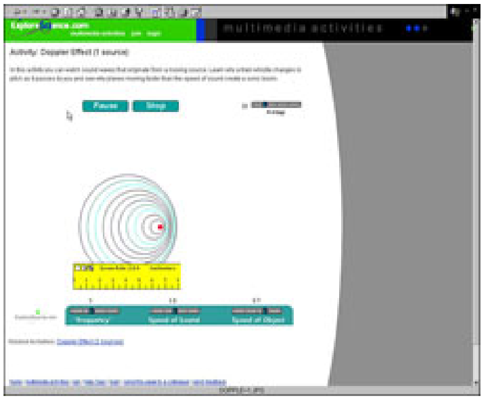
A large body of literature concerning misconceptions supports the notion that learning science is often neither straightforward nor consistent with the conceptions students typically construct from everyday experiences (Minstrell, 1982; Novick & Nussbaum, 1981; Songer & Mintzes, 1994; Wandersee, Mintzes, & Novak, 1994; among many others). Whether described as misconceptions or simply non-intuitive ideas in science (Wolpert, 1992), teachers are faced with concepts that pose pedagogical conundrums. New teachers may not even recognize that these instructional puzzles exist unless they are made explicit through their teacher education course work. Developing the skills for making scientific views more accessible is an example of what Shulman (1987) called developing "pedagogical content knowledge." The profession of teaching, Shulman argued, may be distinguished from other disciplines by the knowledge that teachers develop linking knowledge of content with knowledge of instruction, knowledge of learners, and knowledge of curriculum. Developing new teacher awareness of the pedagogical content knowledge domain and how to add to that knowledge is a central goal of science teacher education.

Appropriate educational technologies have the potential to make scientific concepts more accessible through visualization, modeling, and multiple representations. Secondary teachers may have experienced examples of these technologies in college science courses. Elementary teachers may have had limited experiences in college science. Teacher education course work has the task of providing experiences and linking previous experience with technologies whose purpose it is to provide representations of concepts that are difficult to represent in everyday experience. For example, kinetic molecular theory, an abstract set of concepts central to the disciplines of physics and chemistry, may be easier for students to understand if they can see and manipulate representations of molecules operating under a variety of conditions. Williamson and Abraham (1995) found support for this in their investigation into the effectiveness of atomic and molecular behavior simulators in a college chemistry course. In this study, atomic/molecular simulations were integrated into the instruction of two groups of students, while a third group received no computer animation treatment. The two simulation treatment groups achieved about one half standard deviation higher scores on assessments of their understandings of the particulate nature of chemical reactions. The authors concluded that the simulations increased conceptual understanding by helping students form their own dynamic mental models.

Science education courses should challenge teachers to analyze their teaching experience for pedagogical conundrums, the concepts that are inherently difficult to present to students and/or difficult for students to understand. Once identified, the pedagogical task is to select appropriate teaching strategies and representations of content to address these topics. Digital technologies are an important category of options for approaching these conundrums. For example, a familiar but abstract science concept taught in secondary physical science classes is the Doppler effect. The Doppler effect is commonly defined as the change in frequency and pitch of a sound due to the motion of either the sound source or the observer (see Video 1).

While the phenomenon is part of students' everyday experiences, its explanation is neither easily visualized nor commonly understood. This difficulty stems from the invisible nature of sound waves and the fact that traditional representations are limited to static figures of the phenomenon, which by definition involves movement.

Computer simulations are able to get past these limitations by simulating the sound waves emitted by moving objects (see Video 2). Being able to see representations of the sound waves emitted by moving objects presents new opportunities for understanding by offering learners multiple epresentations. Simulations also allow students to manipulate various components, such as the speed of the object, the speed of sound, and the frequency of the sound emitted by the object. Such interaction encourages students to pose questions, try out ideas, and draw conclusions (see Appendix D, Doppler Effect Simulator and Activities).



Within the context of this type of example, new teachers should be challenged to identify appropriate science pedagogy, as described in Guideline 2.

An important consideration for all teachers when using simulations as models for real phenomena is that, while simulations can be powerful tools for learning science, students must not mistake a simulation —meant to make a concept more accessible—for the actual phenomenon. Students must understand that a sophisticated computer graphic for molecular motion, the Doppler effect, or any other phenomenon is still only a model. Therefore, it is critical that preservice teachers be given explicit opportunities to reflect on the nature of scientific models and the role they play in the construction of scientific knowledge, as well as encouragement and examples for how to address these concepts in their own instruction (Bell, Lederman, & Abd-El-Khalick, in press).

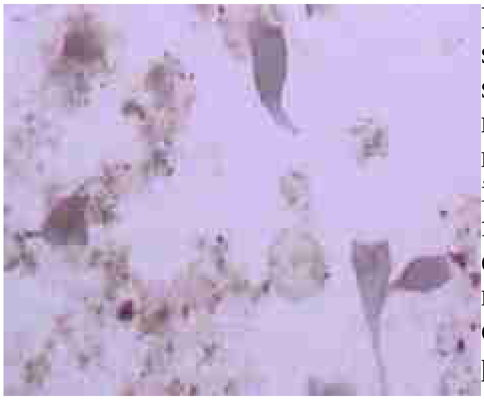
5. Technology instruction should develop understanding of the relationship between technology and science.

Despite Western society's heavy dependence on technology, few teachers actually understand how technology is used in science. Nor can they adequately describe the relationship between science and technology. For example, one of the most common definitions of technology used in schools today is "applied science" (Spector & Lederman, 1990). While this familiar definition seems reasonable at first glance, it ignores the fact that the history of technology actually precedes that of Western science (Kranzberg, 1984) and that the relationship between science and technology is reciprocal (AAAS, 1989). A more appropriate understanding of technology for inclusion in teacher education courses is the concept of technology as knowledge (not necessarily scientific knowledge) applied to manipulate the natural world and emphasizes the interactions between science and technology.

Using technologies in learning science provides opportunities for demonstrating to new teachers the reciprocal relationship between science and technology. Extrapolating from technology applications for classrooms, new teachers can develop an appreciation for how advances in science drive technology, and in turn, how scientific knowledge drives new technologies.

Computer modeling of chemical structures leads to the development of new materials with numerous uses. In reciprocal fashion, high quality computer displays and faster computers make possible types of scientific work impossible before such advances. This leads to new ideas in science.

It is important to realize, however, that such understandings are unlikely to be learned implicitly through using technology alone. Rather, new teachers must be encouraged to reflect on science and technology as they use technology to learn and teach science., When using microscopes, whether the traditional optical microscopes or the newer digital versions (see http://IntelPlay.com/home.htm), teachers can be encouraged to think about how science influenced the development of the microscope and the microscope, in turn, influenced the progress of science. For example, the modern compound microscope began as a technological development in the field of optics in the 17th century. The instrument created a sensation as early researchers, including Antoni van Leeuwenhock and Robert Hooke, used it to uncover previously unknown microstructure and microorganisms. This new scientific knowledge led to new questions. For example, where do these microorganisms come from? How do they reproduce? How do they gain sustenance? Such questions, in conjunction with advances in optics, led to the development of ever more powerful microscopes, which in turn, became the vehicles for even more impressive discoveries. The cycle continues to modern times with the invention of the electron microscope and its impact on knowledge in the fields of medicine and microbiology.



Microteaching and supervised practicum experiences should help preservice teachers recognize that when students are making new discoveries of their own with microscopes, they are well positioned to understand the reciprocal relationship between technology and science. For instance, fifth-grade students who are recording video footage of microorganisms with the digital microscope can easily appreciate the concept that new discoveries lead to new questions, as their curiosity is piqued by their observations of the miniature world that exists in a drop of pond water (see Video 3).

Furthermore, students can see how their questions fuel the desire for new technologies, as they experience the limitations of the microscopes available to them. A skilled teacher can exploit the resulting "teachable moment" to encourage students to consider how their experiences with the technology relate to those of real scientists.

Technologies are simultaneously tools for learning about science and examples of the application of knowledge to solve human problems**.** When new teachers understand technologies as a means of solving human problems, they can be made aware that technologies come with risks as well as benefits. This feature of technology should be represented in instructional objectives and be visible in lesson plans and other relevant assignments. For example, efficiencies of storage and retrieval of information have the associated risks of losing large quantities of data in damaged disks, system malfunctions, or incorrect actions on the part of users. Uses of technology in teacher education courses can emphasize how technologies produce trade-offs, for instance, between gaining more sources of knowledge through the Internet and CDs while at the same time creating a greater expenditure of time and effort sorting appropriate, high quality information.

Summary

The draft guidelines in this paper have been synthesized from knowledge of research, K-12 teaching experience, and teaching experience in science teacher education with technology. They have been drafted to be consistent with national reform goals in science education by examining how these goals might be furthered through the use of modern technologies. Thoughtful reflection on and discussion about these guidelines by a broad range of educators, based on knowledge of diverse areas of educational research and a broad base of teaching experiences, will deepen understanding of how technologies can improve science teaching and the preparation of new teachers of science. Future revisions of the guidelines will reflect the ongoing discussion in *Contemporary Issues in Technology and Teacher Education* that this article is intended to generate.

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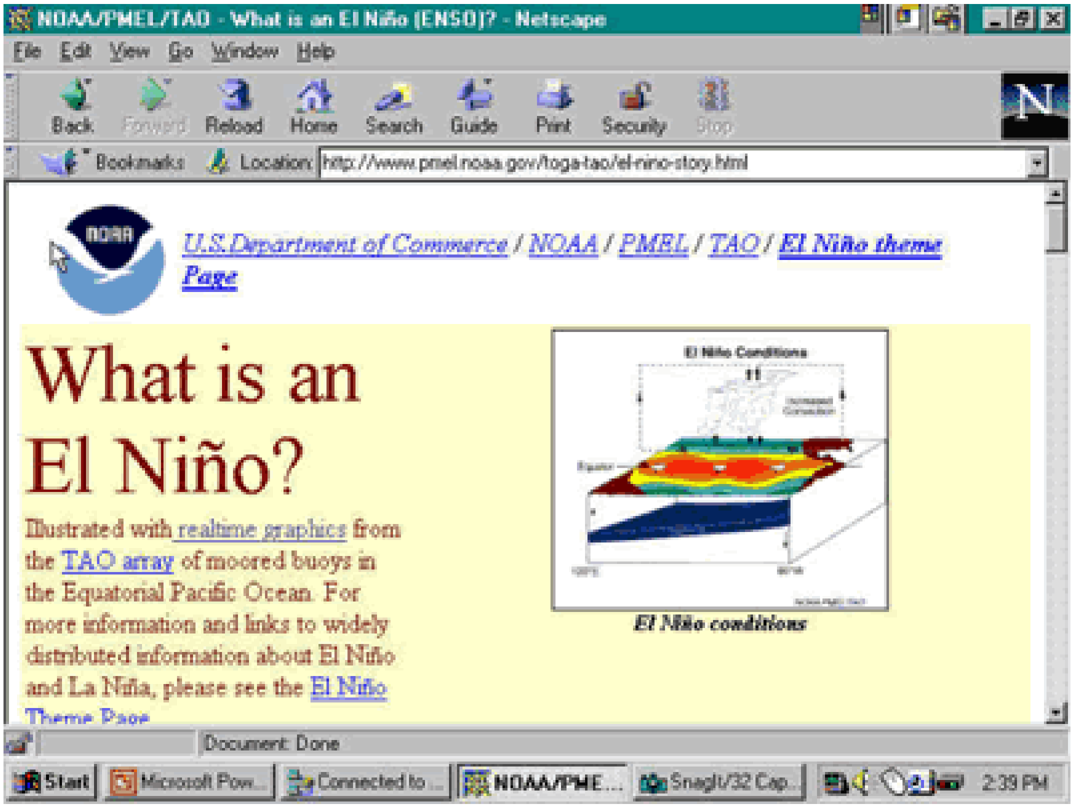
APPENDIX A

WHAT IS EL NIÑO? BACKGROUND RESOURCES



NOAA/PMEL/TAO - What is an El Niño (ENSO)? - Netscape

http://www.pmel.noaa.gov/toga-tao/el-nino-story.html

U.S.Department of Commerce / NOAA / PMEL / TAO / El Niño theme Page

What is an El Niño?

Illustrated with realtime graphics from the TAO array of moored buoys in the Equatorial Pacific Ocean. For more information and links to widely distributed information about El Niño and La Niña, please see the El Niño Theme Page

El Niño conditions

Document: Done

What is El Niño?

Try to answer this question using the Internet. Here are some web sites that might help.

http://www.elnino.com/

This site briefly describes El Niño in laymen's terms.

http://www.pmel.noaa.gov/toga-tao/el-nino-story.html

This site provides more detailed and technical discussion of the El Niño phenomenon. It includes some very good graphics.

http://www.macontelegraph.com/special/nino/html/nino1mov.htm

This site combines some basic information with a neat downloadable movie clip with sound.

http://members.aol.com/windgusts/ElNino.html

This is another site that includes basic discussion of the El Niño phenomenon.

APPENDIX B

ADDITIONAL EXAMPLES OF USING TECHNOLOGY TO ADDRESS WORTHWHILE SCIENCE WITH APPROPRIATE PEDAGOGY

Using Technology to Promote Relevancy

Technology-augmented activities should help students perceive the relevance of science to their personal experiences. Students are exposed to sophisticated computer representations of weather data every day through television weather reports. These reports use integrated displays of cloud patterns, moisture levels, wind, barometric pressure, and temperature. Often these representations go unappreciated or misunderstood. The Internet and desktop computers can help students see the meaning of these data by connecting students with sources of real data representing weather in their region of the country. Further programs offer opportunities for students to contribute data as part of a larger picture of national and global climate. The Global Learning and Observations to Benefit the Environment (GLOBE) project is a multinational program of science education (de La Beaujardiere et al., 1997). Students enter weather data, and graphical tools allow them to manipulate how the data from the region, country, or world is represented (see http://www.globe.gov/). The instructional sequence and outcomes might be outlined as follows: (a) student experience is translated into weather measurements; (b) students enter measurements into a worldwide Internet data base; (c) students manipulate data and forge meaning under the guidance of a classroom teacher; and (d) student understanding and appreciation of personal experiences are enhanced.

The use of motion detectors to graph the position of a student walking toward or away from the detector helps students experience an analytical expression of a common experience. Even at the college level, this type of interactive learning tool enhances student understanding of velocity and acceleration (Svec, Boone, & Olmer, 1995; Thornton, 1987; Thornton & Sokoloff, 1990). Other devices record temperature in real time and represent it on the screen as a thermometer or temperature versus time graph. Classroom work demonstrates that students are better able to separate personal sensations of "hot" and "cold" from physical measurements of temperature (Flick, 1989).

Numerous school science topics can be used to model and resolve situations arising in the physical, biological, environmental, social, and managerial sciences. The use of extended student projects formed the basis for Project-Based Science (PBS) that focused on student-designed problems and investigations (Marx, Blumenfeld, Krajcik, & Soloway, 1997). PBS made extensive use of software for accessing information and data manipulation to support student work on complex problems. Teachers guided students in identifying problems and carrying out procedures for addressing those problems. By focusing on the personal significance of classroom tasks, teachers, supported by computer tools for accessing relevant information, helped students connect science concepts to their own lives.

Using Technology to Promote Understanding of Scientific Inquiry

A national consensus has established the central role of inquiry in science education. "Scientific inquiry is at the heart of science and science learning" (NRC, 1996, p.15). Use of technology should support student understanding of scientific inquiry and how scientific investigations are conceived and conducted. Helping students understand the meaning behind a scientific approach to problem solving requires developing student skills with forms of scientific thinking. To accomplish this task, teachers must provide instructional scaffolding to support student thinking (while remaining aware of developmental constraints (Palincsar,

1986). Teachers must also be mindful of the limited experience students have in systematically thinking through problems. Computer tools are beginning to offer support for this type of complex instruction. A case study of a teacher proficient with a computer modeling program documented development of student thinking skills necessary for controlling variables (Fisher, 1997). The computer model allowed students to isolate and control variables in ways that may be obscured in direct, lab experience, due to uncontrollable variables or the untrained observational skills of students. Another case study showed how software for logging and manipulating data encouraged students to reflect on the meaning of data and choose appropriate representations (Rogers, 1997). In the hands of skilled teachers, modern information technologies can be tools for focusing instruction and providing students with an interactive, educational environment for thinking about and doing scientific investigations.

One of the more difficult aspects of getting students engaged in scientific inquiry is posing questions that are meaningful to students yet open to scientific inquiry. Texts often lead students to think of inquiry as an algorithm, the mythic "scientific method." This is especially true if teachers do not mediate text presentations with supplementary instruction about scientific inquiry. If students cannot see the creative, problem-solving side of scientific work, they often do not believe scientific investigations are meaningful. Addressing this important epistemological question was the goal of a project to develop a software environment for scaffolding scientific activity. Researchers at the Learning Research and Development Center at the University of Pittsburgh have taken as their initial focus the development of tools for displaying and evaluating scientific controversies (Cavalli-Sforza, Weiner, & Lesgold, 1994). The software design effort is developing tools for the graphical display of arguments, evidence, and supporting knowledge. For example, interacting through a system of menus and graphical representations, students can seek evidence in support of a particular theory for the extinction of dinosaurs. The software will advise students of particular data, such as the fossil record, and state why it supports or does not support a particular theory. The computer scaffolding acts as resource for students and an instructional tool for the teacher in developing student understanding of the value of theories in posing scientific questions and the role of theories in establishing the meaning of data.

The Internet offers more free-form opportunities for teachers to develop student thinking skills that support inquiry. The display of earthquake data on a world map can be used to guide students to question why geographic locations form the patterns they do. Through discussion that develops understanding of how the data are gathered and represented in the visual database, students can be prompted to design investigations that lead them to seek related data, such as occurrences of volcanic activity (see, for example, http://volcano.und.nodak.edu/ and http://gldss7.cr.usgs.gov/neis/bulletin/bulletin.html .

Using Technology to Promote Student-Centered Learning

A major goal of learning in science is to develop reflective, independent learning in students. The focus on science as inquiry implies taking contemporary science education beyond teaching just the science processes of the 1960s and 70s. "Inquiry is a step beyond science as process. The Standards combine the use of processes of science and scientific knowledge as they use scientific reasoning and critical thinking" (NRC, 1996, p. 105). In a complete science education, students learn relevant bodies of knowledge, ways to conduct scientific inquiry, and the nature of scientific work. To accomplish this complex task, teachers must promote learning cognitive and social skills that make instruction more student centered.

The TESSI project (Pedretti et al., 1998) integrated the use of multiple technologies. Teachers in the project found that relevant and meaningful use of these technologies required a "departure from the teacher-centered format which characterizes much of traditional science instruction" (p. 573). Observations of classroom instruction revealed high levels of teacher interactions with students, including (a) teachers consulting in small group work, (b) teachers directing the use of resources, and (c) purposeful instruction within the context of larger student projects. More important were specific efforts by the teachers to design

instruction that would put the technologies in the hands of students. As a result of access to relevant technologies, revised curricula that took advantage of these technologies, and instructional designs in which technology played important but supporting role, student interviews and surveys suggested that students gained a stronger sense of purpose and self-direction in their classroom work. Students also found traditional materials, such as texts, laboratory work, demonstrations, problem sets, and field work, valuable supplements to classroom learning. Technology was a catalyst for change, but the energy and direction of change came from the teachers working with students in new ways that put students at the center of the instructional process.

A majority of students interviewed in the TESSI study (Pedretti et al., 1998) commented about learning and learning how to learn. For example, students noted the importance of talking with other students.

"The teacher always says we have to `learn to learn,' it's a little weird but I guess it's true because we're learning how to learn on our own with the different materials that are available, like through other people. (Shelley, Physics 11, Fall 1995)" (p. 585)

In addition to reflecting on the importance of talk in learning science, 52% of students surveyed or interviewed mentioned the structure of instruction and teachers' expressed intentions, and how these factors affected their approach to learning. These students became aware of and acted on teacher goals for learning responsibility, independence, self-reliance, and problem-solving. These results may in part be attributed to capable students in high school science classes and to a large investment in new technologies that has temporarily focused attention on these classrooms. The validity of educational innovations is always learned over time. TESSI is obtaining these results after 6 years duration of the project and the participation of over 3,000 students. These effects are long after initial novelty has worn off and after a broad cross-section of students have experienced the program.

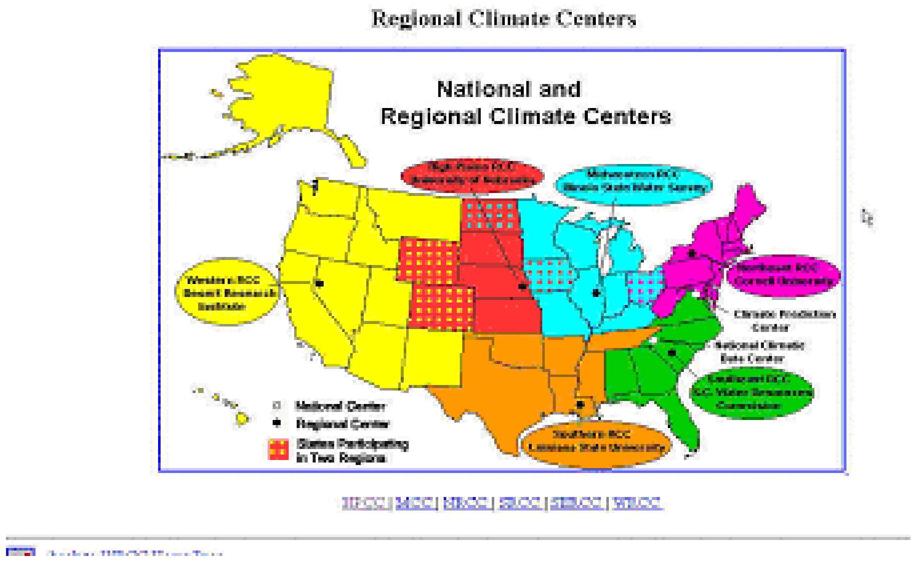
APPENDIX C

EL NIÑO PROJECT

How can I tell if the 1997-98 El Niño has impacted a particular region?

1. First, go to the Regional Climate Center to locate data for the region you are interested in.

http://www.wrcc.dri.edu/rcc.html



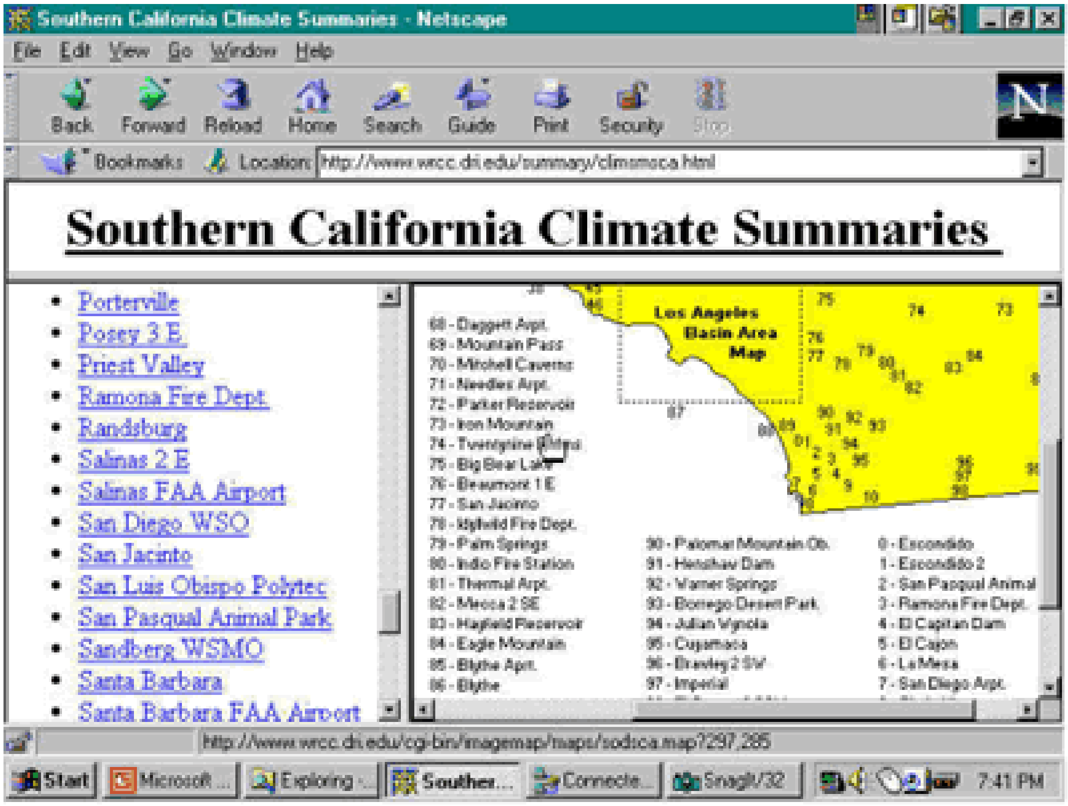
Regional Climate Centers

HPCC | MCC | NRCC | SRCC | SERCC | WRCC

2. Next, find the average monthly temperature and precipitation data. The SERC lists monthly averages for entire states. http://water.dnr.state.sc.us/climate/sercc/region_avg_info.html

Here's a site where you can find monthly precipitation data for select cities in several states: http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html

The Western Regional Climate Center is much better for our purposes, but only includes data for the western states.
· Go to http://www.wrcc.dri.edu/rcc.html. This can be linked to from the Regional Climate Center site shown in step one.
· Select Western U.S. Climate Historical Summaries http://www.wrcc.dri.edu/climsum.html
· Select the state for which you want data
· Select the individual station for which you want data



Southern California Climate Summaries

- Porterville
- Posey 3 E
- Priest Valley
- Ramona Fire Dept
- Randsburg
- Salinas 2 E
- Salinas FAA Airport
- San Diego WSO
- San Jacinto
- San Luis Obispo Polytec
- San Pasqual Animal Park
- Sandberg WSMO
- Santa Barbara
- Santa Barbara FAA Airport

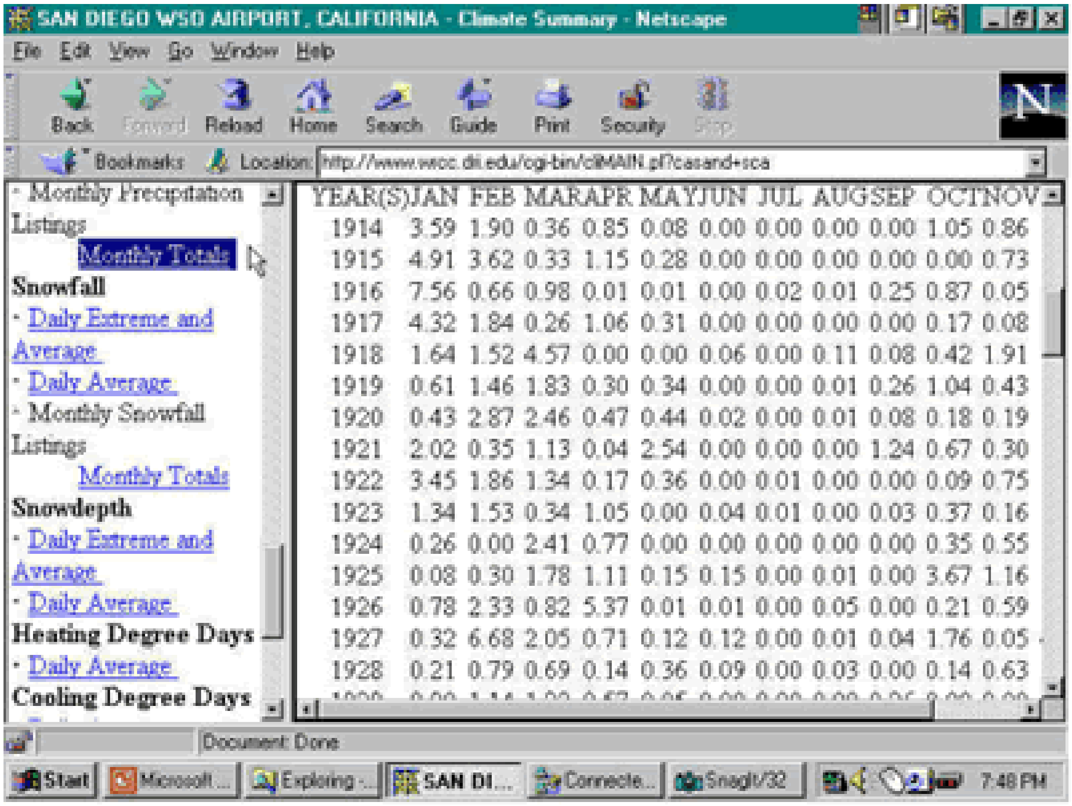
68 - Daggett Arpt.
69 - Mountain Pass
70 - Mitchell Caverns
71 - Needles Arpt.
72 - Parker Reservoir
73 - Iron Mountain
74 - Twentynine Palms
75 - Big Bear Lake
76 - Beaumont 1 E
77 - San Jacinto
78 - Idyllwild Fire Dept.
79 - Palm Springs
80 - Indio Fire Station
81 - Thermal Arpt.
82 - Mecca 2 SE
83 - Hayfield Reservoir
84 - Eagle Mountain
85 - Blythe Arpt.
86 - Blythe

90 - Palomar Mountain Ob.
91 - Henshaw Dam
92 - Warner Springs
93 - Borrego Desert Park
94 - Julian Wynola
95 - Cuyamaca
96 - Brawley 2 SW
97 - Imperial

0 - Escondido
1 - Escondido 2
2 - San Pasqual Animal
3 - Ramona Fire Dept.
4 - El Capitan Dam
5 - El Cajon
6 - La Mesa
7 - San Diego Arpt.

· Scroll down to Temperature in the left frame and select "Average" under "Monthly Temperature Listing"

· Scroll down to Precipitation in the left frame and select "Monthly Totals" under "Monthly Precipitation Listings"

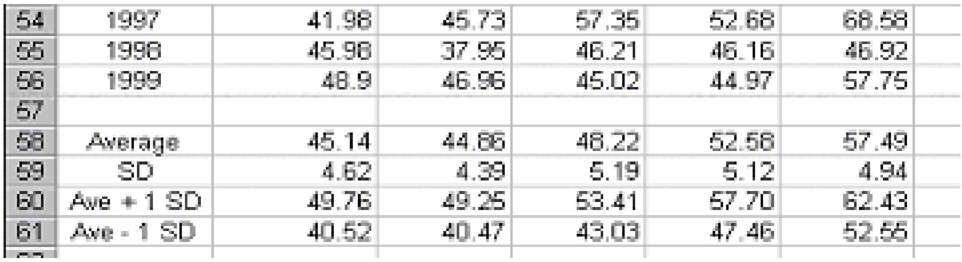


YEAR(S)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
1914	3.59	1.90	0.36	0.85	0.08	0.00	0.00	0.00	0.00	1.05	0.86
1915	4.91	3.62	0.33	1.15	0.28	0.00	0.00	0.00	0.00	0.00	0.73
1916	7.56	0.66	0.98	0.01	0.01	0.00	0.02	0.01	0.25	0.87	0.05
1917	4.32	1.84	0.26	1.06	0.31	0.00	0.00	0.00	0.00	0.17	0.08
1918	1.64	1.52	4.57	0.00	0.00	0.06	0.00	0.11	0.08	0.42	1.91
1919	0.61	1.46	1.83	0.30	0.34	0.00	0.00	0.01	0.26	1.04	0.43
1920	0.43	2.87	2.46	0.47	0.44	0.02	0.00	0.01	0.08	0.18	0.19
1921	2.02	0.35	1.13	0.04	2.54	0.00	0.00	0.00	1.24	0.67	0.30
1922	3.45	1.86	1.34	0.17	0.36	0.00	0.01	0.00	0.00	0.09	0.75
1923	1.34	1.53	0.34	1.05	0.00	0.04	0.01	0.00	0.03	0.37	0.16
1924	0.26	0.00	2.41	0.77	0.00	0.00	0.00	0.00	0.00	0.35	0.55
1925	0.08	0.30	1.78	1.11	0.15	0.15	0.00	0.01	0.00	3.67	1.16
1926	0.78	2.33	0.82	5.37	0.01	0.01	0.00	0.05	0.00	0.21	0.59
1927	0.32	6.68	2.05	0.71	0.12	0.12	0.00	0.01	0.04	1.76	0.05
1928	0.21	0.79	0.69	0.14	0.36	0.09	0.00	0.03	0.00	0.14	0.63

3. Import the two data lists into Microsoft Excel (or a comparable spreadsheet). Since data sets on the Web are typically not saved in Excel format, you will usually find it necessary to first save the data as a *.txt file before you try to open it in Excel. Upon opening the data set in Excel, the program will provide a "Data Import Wizard," which will help you properly format the data in a few easy steps.

4. Calculate a separate average for the temperature data for each month. Students will often want to compare the average temperature data for each month of the entire data set to that of the El Nino year. This is a good time to discuss the differences between an average temperature and a normal temperature range. When comparing data that vary, it is important that the comparison reflect the variability of the data. Therefore, comparing means alone is not very useful. A better approach is to use some measure of variability about the mean, such as standard deviation, if the data reflect a normal distribution. If the data distribution is significantly skewed, it may be more appropriate to use upper and lower quartile ranges about the median. The important point is that the comparison reflects the variability of the data, so that we are comparing a *typical* temperature range to the El Nino year. So, for example, if the data are normally distributed, you could calculate the standard deviation for each month. Next, create a row that calculates the Average + One Standard Deviation, and a separate row that calculates the Average -One Standard Deviation.

Hint: You might want to click on the .00→.0 button a couple times to decrease the number of decimal places.

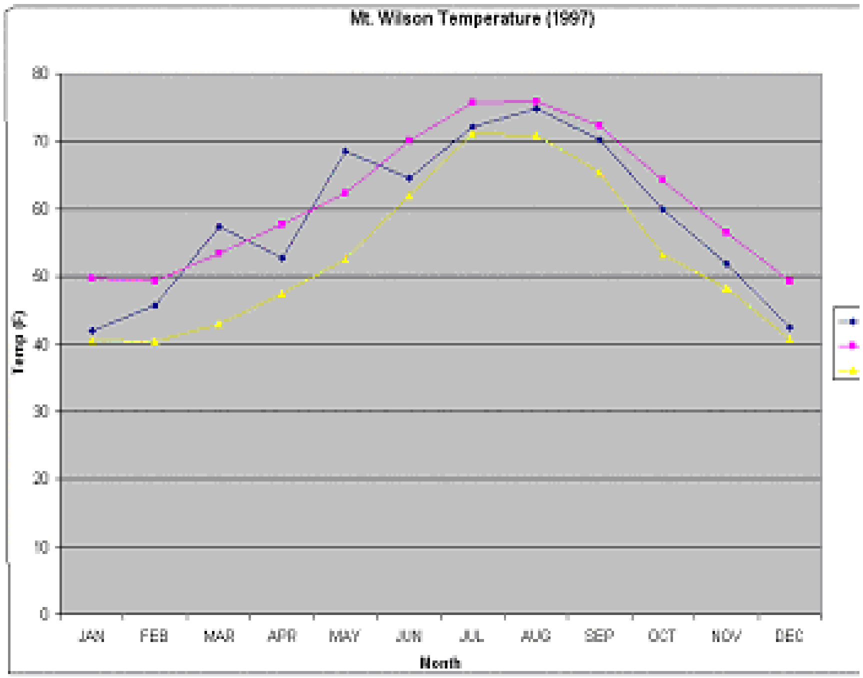


54	1997	41.98	45.73	57.35	52.68	68.58
55	1998	45.98	37.95	46.21	46.16	46.92
56	1999	48.9	46.96	45.02	44.97	57.75
57						
58	Average	45.14	44.86	48.22	52.58	57.49
59	SD	4.62	4.39	5.19	5.12	4.94
60	Ave + 1 SD	49.76	49.25	53.41	57.70	62.43
61	Ave - 1 SD	40.52	40.47	43.03	47.46	52.56

5. Graph three lines on a single graph:

· Average + 1 standard deviation

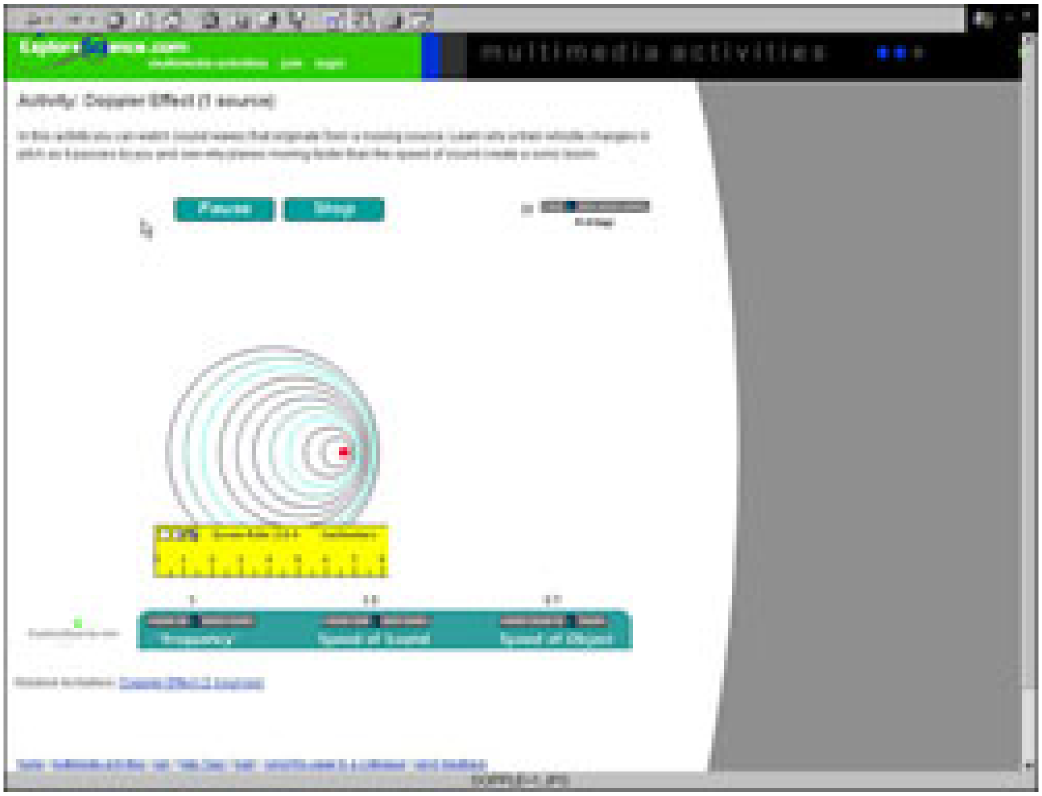
· Average -1 standard deviation
· El Niño year in question (make two graphs, one for 1997 and one for 1998)
For example, your 1997 graph might look like this:



6. Where the El Niño year line falls outside your 1 standard deviation boundaries, you can say that the El Niño temperatures for that month were warmer (or colder) than about 70% of your data. This may be enough to conclude that El Niño had an effect on that particular region, or you may decide that stronger evidence is necessary. For instance, you may decide that the El Niño temperature must lie at least 2 standard deviations from the mean before you are willing to consider the difference significant). This is a good time to have a discussion about what it might take for scientists to conclude that El Niño had an effect.

APPENDIX D

DOPPLER EFFECT SIMULATOR AND ACTIVITIES



Suggested Activities for Exploring the Doppler Effect Simulator at ExploreScience.com

Use the following activity suggestions with the ExploreScience Web site
(http://explorescience.com/activities/Activity_page.cfm?ActivityID=45)

1. Set the "Speed of Object" slider to "0."

· Compare the wavelengths (distance between individual waves) as you adjust the "frequency" slider to a high number (say, 4) and a low number (say, 2). Which would produce a higher pitch?

· Adjust the "frequency" slider back to 0.3 and press the "Start" button. Notice the pattern of waves that is produced. Would you describe it as regular on all sides or skewed? Would the pitch of the sound produced by the object be equivalent on all sides? Repeat with different frequencies (but keep the speed of object at 0).

2. Set the "Speed of Object" slider to "0.6" and press the "Start" button.

· Notice the pattern of waves produced as the object moves across the screen. Would you describe it as regular on all sides or skewed?

· Would the pitch of the sound produced by the object be equivalent on all sides? How does this compare to when the object was stationary?

· How would the pitch of the sound emitted by the object change if it were approaching you? How would it change if it were moving away?

· Relate the motion of the object to the change in pitch an observer experiences as the object approaches and passes by. Why does the pitch change occur (think of the motion of the object in relation to the motion of the sound waves it emits)? Would an observer inside the car hear the change in pitch? Why or why not?

3. Other things to try:

· Notice what happens to the sound waves preceding the object as you adjust its speed closer and closer to the speed of sound (1.0). Is the Doppler Effect most pronounced when the speed of the object is near to that of sound, or when it is much less than the speed of sound? Why?

· What do you think will happen to the sound waves preceding the object when you set the speed of the object equal to the speed of sound? Try it and see! The object is traveling at the same rate as the waves emitted in front of the object, causing the waves to "pile up." This piling effect produces what is commonly referred to as the sound barrier.

· What pattern of waves do you predict when you increase the speed of the object to higher than the speed of sound? Again, try it and see. Now, the object is actually outrunning its own waves. The v-shaped "wake" of sound waves traveling behind the object produces a sonic boom when they reach an observer. What do you think an observer traveling inside the object would hear?

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