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Guest Editorial: Technology Proficiencies in Science Teacher Education

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The mission of the Association for Science Teacher Education (ASTE) is to promote leadership in and support for those involved in the professional development of teachers of science. The organization originated in the late 1920s through visits and meetings to discuss science teacher education standards among faculty members of teacher education institutions in the northeast region of the United States. Eventually, the "Conference on the Education of Science Teachers" became a national organization. In 1953, the members of the conference voted to change the name to the Association for the Education of Teachers in Science (AETS). The name was revised in 2004 to the present ASTE.

The leadership of the organization met in 1993 to establish the present mission statement and to create goal statements to guide the organization into the future. One of these goal statements was "to produce and promote guidelines for improving science teacher education." In 2002, an ad hoc technology committee was created to provide leadership through technology-based workshops and sessions and to assist with the selection of the new National Technology Leadership Initiative award for science education. This committee consisted of professionals who integrated instructional technology in their teaching, developed new technologies or methodologies implementing technology, and researched the effects of technology in the learning and teaching of science and science education.

Although there had been previous examples of creating guidelines for instructional technology for teacher education (Flick & Bell, 2000; ISTE, 2002), the ASTE had no guidelines or position papers specifically for technology in science teacher education. In 2004, the ASTE Technology Committee co-chairs, Alec M. Bodzin and John C. Park, began working with the committee to establish a position statement on technology in science teacher education on behalf of the organization. In 2005, the ASTE board of directors revised and approved the document (see appendix). They also changed the status of the Technology Committee from ad hoc to standing committee.

Using technology as a tool for science inquiry by pupils in the school science classroom and laboratory is the central theme of the ASTE position statement. This is congruent with the *National Science Education Standards* (National Research Council [NRC], 1996), which emphasized that science should be learned using inquiry methods. The methodologies related to using technology tools in school science discussed in the ASTE document can be categorized into four broad groups: (a) Gathering scientific information; (b) data collection and analysis by pupils; (c) creating and using models of scientific phenomena; and (d) communication.

Gathering Scientific Information

Thirty years ago, when a pupil needed to find information about a topic in science, they might have been able to find it in reference books in the classroom, or they could go to the library and search through encyclopedias or journals. Today, in the Internet Age when computers are easily accessed, when more information is needed about a specific topic, most people use a search engine on the Web. This is no less true for pupils in school science. If pupils need to find out about the specifics of a certain element, they can search the Web to find WebElements™, and with a click of a button they can find interesting facts about any element from the periodic table. If they want to locate information about the North America robin, a search would probably turn up the Cornell Lab of Ornithology, where abundant information about many species of birds could be easily reviewed.

Locating resources is much easier than it has been in the past due to the use of information technology. However, learners must evaluate the resources they discover. Most anyone can publish a Web page, whether the information found in the site is factual or not. Preservice science teachers need the skills to evaluate the validity of Web sites.

Bodzin (2005) created an instrument (Web-based Inquiry for Learning Science – WBI) that guides teachers to identify Web-based inquiry activities for learning science. The WBI directs the teachers to classify those activities along a continuum from learner-directed to materials-directed for each of the five essential features of inquiry (NRC, 2000). Instruments of this type help preservice science teachers develop the evaluation skills necessary to select appropriate Web sites for inquiry activities in the classroom.

Scientific information can also be collected and distributed via the Web to enhance science learning. Although there are numerous projects on the Web that allow pupils and scientists to collaborate in the data collection and analyzation process, one such project is the GLOBE project (http://www.globe.gov). The GLOBE project can be used by elementary through secondary pupils to learn about ecology and biology. Bombaugh, Sparrow, and Mal (2003) illustrated how this process can help foster inquiry learning in a high school biology class. The use of secondary data is highly desirable when the pupils are unable to measure and collect the data themselves. However, whenever possible the national standards promote student collection of data for subsequent analysis.

Data Collection and Analysis by Pupils

The science curriculum projects of the late 1950s and 1960s focused upon posing problems for pupil investigations. The curriculum provided additional media and materials to aid pupil understanding of the concepts being studied. Science process skills were emphasized, and the school science laboratory was the center of learning. The *National Science Education Standards* (National Research Council, 1996) embraced the same philosophy. The science teaching standards include the following:

- Teaching Standard A: Teachers of science plan an inquiry-based science program for their students.
- Teaching Standard B: Teachers of science guide and facilitate learning.
- Teaching Standard D: Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.
- Teaching Standard E: Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

Data can be collected from a variety of sources, measurements can be made from events that happen within the classroom, quantitative and qualitative data can be measured or observed from still or moving images, and data can be “mined” from the Web that pupils can analyze. The next few sections discuss methodology for collecting this data through images, graphics, and probeware.

Scientific Visualization

The teaching of school science has a history of invention and use of instructional technology. A review of early school science textbooks reveals an extensive use of representative and analytical drawings and photographs. Early projection devices, called “magic lanterns,” projected photographic images developed on glass plates. Soon after motion picture cameras and projectors were invented, science teachers were using moving picture technology in their classrooms. Before the advent of talking-pictures, societies promoting visual education encouraged the use of both still and moving images in all course subjects. Early science teachers wanted to “fix” the images that pupils were viewing or drawing onto the pupils’ minds, much as chemicals fix the photographic image onto film.

From that early history, the importance of the use of images in science education was never disputed. Whether the image is on a glass plate and is projected on the wall in a science classroom in 1905, or the sequence of images is viewed in a QuickTime™ movie on the Internet in 2005, the science teacher needs to emphasize the power of keen observation skills.

Media that display scientific visualizations consist of two main types: Images of actual objects (photographs); or graphics of objects, graphs, or other representations of ideas or data. For example, a photograph of common table salt can be used to show the color and general cubic shape of the salt grains. An electron microscope may produce an image of the surface of the salt crystal; however, the orientation of the particles that make up the salt crystal would most likely be shown in a graphic, with spheres representing the sodium and chloride ions in a specific pattern. A pupil could watch a movie of a salt crystal slowly dissolving in water, or the pupil could watch an animation of the molecular bombardment by the water molecules on the crystal, and subsequent dynamic distribution of the ions amongst water molecules. The different visualizations of the same phenomena yield different understandings about what is happening.

Linn (2003) reported that visualizations of abstract phenomena are most useful. For example, complex data sets can be made into visualizations that describe weather patterns, molecular structures, heat flow, and geologic structures. She warned, however, that some representations can either mislead pupils or reinforce intuitive ideas. For example, pupils attributed features to individual molecules that are actually attributed to the aggregate of molecules such as color, viscosity, or structure after interacting with molecular visualizations.

Sandvoss et al. (2003) described the development of the Common Molecules graphics collection. This is a Web-based resource of interactive 3-D representations of molecules. These molecular representations can be viewed as wire models, ball and stick models, or space filling models. Pupils can click and drag on the images to view the molecules from various perspectives. There are options to view them using special glasses that produce the anaglyph 3D effect.

Image Analysis

Geographic Information Systems technology is a tool that empowers pupils to engage in real-life scenarios while they identify problems, hypothesize, collect data, develop procedures, and produce workable results that they communicate to others (Ramirez & Althouse, 1995). Research by Baker (2002) included eighth-grade Earth science pupils who studied local air quality indicators using GIS. The GIS pupils showed a modest improvement in their integration of science process skills, particularly data analysis (geographic and mathematical) activities. Hagevik (2003) found that using GIS may aid pupils in constructing concepts and in promoting understanding of environmental content, problem solving, experimental design, and data analysis and in communicating findings to others.

The video technology of 2005 enables pupils to analyze motion electronically. Using a digital video camera on a tripod, video editing software, and video analysis software, pupils can shoot, edit, and analyze one- or two-dimensional motion.

Suppose a pupil desires to analyze the motion of a toy “pull-back” car. The pupil sets up the event on a table where the motion will be perpendicular to the line between the video camera and the event. Included in the scene is an object of known length that is the same distance from the camera as the motion event. The pupil starts the video camera and begins the motion event; once recorded, the digital information can be transferred to a video-editing program where only the most salient motion is kept. The pupil creates a title page that gives pertinent information regarding the event, such as the title of the event, the creators of the video, and the mass of the pull-back car. The edited video is saved as a QuickTime movie. The analysis software is opened and the movie is imported into the software. With a click of a few buttons, the movie is scaled to the desired size, the reference length in the movie is calibrated, and then the pupil places a point on the front bumper of the car. The movie advances to the next frame for another point. This process continues until the pupil completes each frame in the video. Since the computer has stored the frame rate of the video, and the calibrated distance from one point to the next in each succeeding frame, the computer can compute distance, velocity, and acceleration during the motion of the object. Having the mass of the car stored in the computer memory, the net force acting on the car can be calculated at regular intervals of the video.

Another motion analysis technique would be to create a “stop-motion” animation movie. Instead of creating motion and videotaping the event, the pupil would create individual frames of an object with slight variation of position between subsequent frames. Knowing the distance the object is moved, and the frame rate used in assembling the movie, the object would be seen traveling at a specific rate. See Park and Bell (2005) for specific details on the creation and use of stop-motion animation in physical science activities.

Probeware and Analysis Software

Probeware is the term describing the use of transducers that change measured physical quantities into electrical quantities that can be interpreted by microprocessors. These transducers react to changes in physical environments such as temperature, pressure, force, or pH. Most transducers, or probes, connect to interfaces that are, in turn, connected to microcomputers, calculators, or palm devices. A calibrated device can be interpreted by the microprocessor, and the data can be displayed in tabular or graphic form. The transducer, interface, microprocessor, and software can be collectively referred to as probeware. For examples of the wide variety of probeware available, check Vernier Software and Technology (http://www.vernier.com/) and PASCO (http://www.pasco.com/), both of which market many of the common probeware systems to schools.

The first study of probeware with children occurred in 1982 by Tinker and Barclay. Tinker reported that this was the “first indication of the power of kinesthetic real-time interactions to lead to understandings of abstract representations” (Tinker, 2000, p. 7). In the same study, the short exposure of pupils to the apparatus helped them to have an intuitive understanding of decimal numbers. Mokros and Tinker (1987) later found that if pupils walked back and forth in front of a motion detector while they were watching the graph of their motion they could quickly learn to interpret position graphs.

In that same year, Brassell (1987) reported that the simultaneous display of the real-time data resulted in significant learning, whereas a delayed display of the data did not. The use of the displayed data to encourage pupil learning was confirmed in a study by Russell, Lucas, and McRobbie (2003). They ascertained that “students used the display, almost exclusively, as representing the experimental phenomena or task problem” (p. 225), “the nature of the display was supportive of a deep approach to learning” (p. 229), “students critically evaluated the appearance of the graphic display” (p. 230), and “the kinematics graphic display supported students’ working memory” (p. 234).

The use of probeware in itself is not the “magic pill” for learning in science education. Tailored designs of data collection and representation technology are required for best results. Linn and Hsi (2000) reported that after a series of eight iterations of changes in a 12-week thermodynamics curriculum, using real-time data collection resulted in a 400% increase in pupil understanding of the differences between heat and temperature. This research led to a new framework called scaffolded knowledge integration, which offers principles of experimental design for learning science and practices that promote knowledge integration (Linn, 2003).

Laboratory activities using probeware are also not inherently inquiry activities, as the probeware could be used in “cookbook” fashion. Royuk and Brooks (2003), however, found that when probeware was designed to be used in an inquiry-based manner learning was increased compared to traditional cookbook labs in a college physics class. Slykhuis (2004) demonstrated that inquiry-based curriculum that incorporates the use of probeware could be effectively delivered over the Web to high school physics pupils.

The power of probeware is real-time data collection. However there is only one time-based activity where the pupils are looking at the collected data as the exploration continues: using the motion detector while walking, trying to match pre-existing graphs. For most other explorations, the user begins the data collection, turns his/her attention to the event to watch it to completion, and then turns back to the computer to see the results. The next generation of probeware merges visualization with analysis. Vernier Software and Technology's Logger Pro has the capability to synchronize the collected data and resulting graph with a movie of the event. If a digital video captured the event as the data is being collected with the probe, the resulting digital video can by synched to the data. Pupils can scroll across the graph and view the movie simultaneously, stopping and starting, or replaying critical regions of the graph to see exactly what is happening in the event during interesting points on the graph.

Atar (2003) questioned high school AP chemistry pupils as to the strengths and weaknesses of using probeware. The pupils reported they enjoyed and valued the probeware activities, and over 90% expressed a desire to complete more in the future. Among the few frustrations expressed by some pupils was a sense of detachment from the event as the data were collected by the computer and a struggle to be aware of the scale of the computer-generated graphs.

Creating and Using Models of Scientific Phenomena

Data collection and pattern recognition are essential components for the predictive power of the scientific method. Pupils can take data collected from an investigation and use tool software to investigate the relationships among variables. For example, a pupil can use probeware to collect data on an object in free fall. Using data analysis software, the pupil can explore the relationship between position and time using a curve-fitting option. After discovering that the quadratic equation is the best fit for the data, the pupil applies meaning to the variables in the equations, and one of the fundamental kinematic equations is discovered. This mathematical model can then be used to predict distances objects travel in free fall for a given amount of time. This is one aspect of modeling: pupil generated models.

Clement (2000) stated that part of scientific investigation is creating, testing, and revising models. Further, Hestenes (1987) suggested that mathematical modeling of the physical world should be the central theme of physics instruction. Hestenes defined a model as a representation of structure in a physical system and/or its properties. Using this idea, models can be mathematical or physical representations.

Once a model is created, it can be simulated. Simulations can be computational, graphical, or a combination of both. Those who operate the simulation are able to change variables in the model and view the results. An example of a graphical simulation with a hidden mathematics framework is a solar eclipse simulation found on the NC State Science Junction Web site (http://www.ncsu.edu/sciencejunction/depot/simulate/eclipse98/visualize.html). Pupils can explore this simulation by selecting two locations from which to view the 1998 total solar eclipse. After observing the simulation, pupils find patterns in what is observed. An example of a graphic model that does not use factual mathematical modeling of the event nor uses proper scaling is also found on the Science Junction Web site (http://www.ncsu.edu/sciencejunction/station/gameroom/react/index.html). The intent of this simulation is to emulate conditions necessary for a reaction to occur: molecules must collide, collide with appropriate energy, and collide with correct molecular orientation. A factual, mathematically correct simulation is not necessary to demonstrate the conditions for a reaction.

Stieff and Wilensky (2003) used chemistry simulation software that allowed pupils to explore how atomic/molecular microlevel changes result in macrolevel changes. The results suggested that pupils who interacted with the software tended to move away from memorized answers and toward conceptual questions and attempted to answer with more reasoning and justification. Williams, Chen, and Seaton (2003) examined the effectiveness of haptics-augmented computer simulations with sixth-grade pupils. Inexpensive commercially available joysticks with haptic feedback were paired with online simulations of simple machines. The preliminary results suggested that the pupils thought the devices were effective. The pupils reported enjoying the activities with minimal or no technical difficulties in their use nor the navigation of the sites.

Simulation software can be used to teach traditionally hard to reach pupil groups. Huppert, Lomask, and Lazarowitz (2002) studied the effect of computer simulation software dealing with the growth of microorganisms on high school biology pupils. The research included 181 pupils in two groups, one with the simulation software, lecture and lab activities, and one with traditional lecture and lab activities. Results suggested significant gains for the treatment groups over the control group for the concrete and transitional operational learners, regardless of gender. There was no difference between the groups with formal operational pupils.

Since simulations are often highly visually dependant, Yang, Andre, and Greenbowe (2003) studied the effect on the use of animations in a college chemistry course. Over 400 students were given a visualization pre-test, in an effort to determine if animations were more or less effective for those with higher visual-spatial abilities. Animations resulted in increased achievement on the post-test on the chemistry concepts. There was some ambiguity as to whether students with higher visual-spatial ability were able to benefit more from the animations.

Communication

The *National Science Education Standards*, Teaching Standard E, begins, "Teachers of science develop communities of science learners..." (NRC, 1996, p. 45). It is understood that the "glue" that keeps the communities together is communication. Internet-based communication tools include email, lists, forums, blogs, wikis, and Web sites. Recent research has clarified the contributions of collaborations and discussions as relates to science learning.

Most studies stated that having the tools themselves are not enough to establish a well-developed network of peers. There must be a structure to the development of the community, a common goal, or a common problem to solve. Scardamalia and Bereiter (1992) developed a series of prompts to guide contributions to promote evidence-based discussions. Bodzin and Park (2000) required preservice science teacher participants to place a forum posting to the Critical Incidents in the Science Classroom topic on their Web forum. Critical incidents are defined as an event that confronts teachers and makes them decide on a course of action that involves some kind of explanation of the scientific enterprise.

Other forms of communications that classroom teachers have implemented with their pupils is to require the pupils to communicate the result of their explorations using slideware presentations, or by creating a Web site of their work. Boxie and Maring (2002) reported the results of a successful project with preservice science teachers and eighth-grade pupils. Working through the Web, the pupils collaborated on completing a science investigation and writing project. Both sets of pupils reported the benefits of this method of communication.

Future Directions

The ASTE position statement on Technology in Science Teacher Education encompasses a broad spectrum of technology use. However, research on the pupil use of the technologies has not kept pace with development of the technology. Perhaps researchers are more interested in researching the latest new invention instead of implementing extended research on the technologies that are evolving and maturing. For example, one technology that shows a great deal of promise is the synchronized movie analysis of data using probeware. If the real-time data collection using probeware makes a difference in pupil understanding of science concepts, being able to study the data with synchronized movies extends this idea to a higher level. Yet, since probeware has been available for over 20 years, it may not have the appeal for research as the latest “gizmo” might have.

Scientific visualization has been accepted as a means of instruction in school science with little research on how students use images. With newer research capabilities using eye-tracking, more studies could occur related to what and how students view when interacting with either a still or moving image. Are the students focused on the critical features of an image, or are they distracted by what is unimportant? Can student experiences using visual technology be tailored to enhance their spatial abilities?

As the technology becomes smaller and less expensive with more capabilities, how will this enhance our quest for student inquiry? When video cameras are reduced to the size of a dime and can transmit the image wirelessly over greater distances, how will science teachers use this technology? And does this technology assist those students who are physically challenged, or does the technology broaden the opportunity gap? It is our hope that we not only research the capabilities of new technologies, but also to continue to research the effect of the older technologies that have matured in the past few decades.

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Appendix

ASTE Position Statement on the Technology in Science Teacher Education Approved July 2005

Technology-integrated materials when used appropriately can enhance science teaching and learning. It is therefore the position of the Association for Science Teacher Education that the qualified science teacher educator should possess a strong knowledge base in understanding how implementing technology in science curricular contexts may be used to promote the teaching and learning of science. Technologies such as Web-based resources, real-time data collection with probeware, simulations, Geographic Information Systems, and real-time video-conferencing offer science teachers new opportunities for creating learning environments that meet the needs of diverse learners.

Science teachers can promote student-centered, inquiry-based learning with activities involving technology-based materials. In addition, Internet-based telecommunications offer science teachers opportunities to expand their professional networks beyond the walls of the school building.

To effectively integrate technology in the preparation and development of science teachers, science teacher educators should:

- Identify and locate technology-based materials and resources and evaluate them for suitability and accessibility for science instructional purposes.
- Understand how integrating technologies into science instruction can enhance science teaching and learning for all.
- Model technology-based science curricular activities with appropriate pedagogy.
- Design activities involving technology-integrated materials to promote student-centered, inquiry-based learning for all.

The following are examples of how technology-based materials may be used to promote science teaching and learning.

- Support student investigations with real-time data collection via hand-held or microcomputer-based probeware.
- Use scientific visualizations to show phenomena that cannot be seen with typical classroom resources.
- Use a simulation to explore a complex scientific phenomena.
- Use multimedia resources, such as animations, video clips, or still images to illustrate science content, concepts, or processes.
- Use distributed information sources such as real-time data, online databases, peer groups, and mentors/experts in many locations to investigate scientific questions.

- Use Web-based photojournals and virtual field trips to explore remote geographic locations.
- Use Geographic Information Systems (GIS) to visualize, manipulate, analyze, and display spatial data.
- Engage in a Web-based inquiry activity to investigate a scientifically oriented question.
- Use a spreadsheet or database to analyze a data set.
- Incorporate Web-based primary sources for guided explorations and information-gathering research tasks.
- Use telecommunication networks, such as a listserv or Web-based forum, to collaborate on a project or
communicate conclusions from an investigation.
- Use modeling tools to build, test, and revise scientific explanations and represent scientific understandings.

Note: This position statement is congruent with the best technology integration practices from the International Society for Technology in Education's (ISTE) *National Educational Technology Standards*, the National Science Teachers Association's (NSTA) *Position Statement on the Use of Computers in Science Education*, and the *National Geography Standards*.