FORUM ON TECHNOLOGY IN K-12 EDUCATION: ENVISIONING A NEW FUTURE
SCIENCE

Steven J. Rakow
Professor, Science Education
Chair of Curriculum and Instruction
University of Houston-Clear Lake
and
Retiring President
National Science Teachers Association

At first glance the classroom seemed to be chaos. Mr. Jackson's fourth graders were spread throughout the classroom, huddled in groups, working on different tasks. Four students were accessing the Internet to download information about different kinds of bridges. Another group, building a model of a suspension bridge, was using a hand-held calculator to predict the weight that their model bridge could hold before collapsing. Another group clustered around a speaker phone firing questions at a mechanical engineer on the other end of the line who was helping them to refine their design while a fourth group was using the on-line encyclopedia to research the history of bridges and bridge building for their background report. The last group was using presentation software to develop a report to give to the class describing their bridge design.

Does this sound like a future scenario? For many schools it is. Yet none of these are technologies that are new or potentially unavailable to our nation's teachers and students.

WHAT IS TECHNOLOGY?

Before we can envision a future for technology in K-12 science education, we need a starting point, and a good starting point is to first define “technology.” For a science educator, technology refers to much more than computers, CD-ROMs, and the Internet. These devices, which we will call “instructional technologies,” represent the application of technology to the teaching and learning process.

Perhaps the International Technology Education Association best encapsulates the science educator's notion of technology in their logo, “Technology is Human Innovation in Action!” They go on to define technology as having five dimensions:

- Designing, developing, and utilizing technological systems
- Open-ended, problem-based design activities
- Cognitive, manipulative, and affective learning strategies

- Applying technological knowledge and processes to real world experiences using up-to-date resources

- Working individually as well as in a team to solve problems."

In the late 1980s and early 1990s, the American Association for the Advancement of Science embarked upon a landmark project entitled Project 2061. The goal was to reform science education. Part of this process involved identifying what scientifically literate Americans should know about science and how this should effectively be taught. *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) was the document in which they laid out this scope and sequence of science and to define the connections between and among science, mathematics and technology. They defined technology as:

> "Technology is an overworked term. It once meant knowing how to do things—the practical arts or the study of the practical arts. But it has also come to mean innovations such as pencils, television, aspirin, microscopes, etc., that people use for specific purposes, and it refers to human activities such as agriculture or manufacturing and even to processes such as animal breeding or voting or war that change certain aspects of the world. Further, technology sometimes refers to the industrial and military institutions and know-how. In any other senses, technology has economic, social, ethical, and aesthetic ramifications that depend on where it is used and on people's attitudes toward its use." (page 43)

Similarly, the *National Science Education Standards* (National Research Council, 1996) considers "Science and Technology" to be one of the eight content standards. According to this document (page 106),

> "The science and technology standards … establish connections between the natural and designed worlds and provide students with opportunities to develop decision-making abilities. They are not standards for technology education; rather, these standards emphasize abilities associated with the process of design and fundamental understandings about the enterprise of science and its various linkages with technology."

The National Science Teachers Association document, *Pathways to the Science Standards: Middle School Edition* (Rakow, 1998) describes the progression of understanding of technology envisioned by the *National Science Education Standards*. Students in the elementary grades develop simple design applications that do not distinguish between science and technology. As they move into the middle grades, they begin to distinguish between science and technology in their designs and compare the work of scientists and engineers. Finally, at the high school level, the students are conceptualizing much more complex technological solutions for problems and evaluate the consequences of these solutions in terms of societal implications.

Hence, for the science educator, the term "technology" takes on a much broader context than instructional technologies. Technology encompasses the wide range of endeavors, including identifying appropriate problems for technological design, designing a solution or a product, implementing a proposed design, evaluating completed technological designs or products and communicating the process of technological design. Given that context, the remainder of this paper will focus on "instructional technology ."

WHAT IS THE CURRENT IMPACT OF INSTRUCTIONAL TECHNOLOGIES ON K-12 EDUCATION?

Nicholas Negroponte, Mitchel Resnick, and Justine Cassell (1997) from the Massachusetts Institute of Technology Media Lab argue that "digital technologies can (and should) transform not only how children learn, but also what children learn, and who they learn with." The promise of digital technologies is that children will become more active and independent learners with a broader access to information and resources than ever before. This is certainly compatible with the message of the *National Science Education Standards* which has as its key premises that all students will learn science through an active process using applications to real-world experiences and issues. Thus, instructional technologies are a natural match with science education.

Any discussion of the future impact of instructional technologies should have a grounding in the realities of today's classrooms and communities. According to the National Center for Educational Statistics (1998), by 1998, 89% of schools and 51% of instructional rooms had access to the Internet. This represents a rapid growth from 1994 in which only 35% of the schools and 3% of the classrooms had Internet access. Although there is little difference in school access to the Internet in schools with differing demographic profiles, the issue of classroom access varies greatly. In schools with less that 6% minority enrollment, the percentage of instructional rooms (classroom, computer lab and library/media center) with Internet access was 57%, but in schools with 50 percent or more minorities, that number fell to 37% of instructional rooms. In schools with less that 11% of the students on free or reduced lunch, 62% of the instructional rooms had Internet access, but in schools with 71% of more of students on free or reduced lunch, only 39% of the instructional rooms had access to the Internet. Certainly the Telecommunications Act of 1996 has been a significant factor in this growth by making telecommunications services accessible to schools at a reduced rate[1].

Another measure of technology access is the ratio of students to computers. According to the President's Committee of Advisors on Science and Technology (1997), the optimal ratio is 4 to 5 students per computer. In the Fall of 1998 there were approximately six students for every instructional computer and this number did not vary among schools with differing demographic profiles (National Center for Educational Statistics, 1998). The number of students per instructional computer with Internet access, however, did vary with school demographics. Schools with less that 6 percent minority enrollment or less than 11 percent free and reduced lunch had a ratio of 10 students per Internet accessible computer whereas schools with 50 percent or greater minority enrollment and schools with 71 percent or more free and reduced lunch had a ratio of 17 students per instructional computer with Internet access.

These data illustrate that there has been an incredible growth in Internet access to schools and classrooms and growth in the student use of computers and the Internet. Given this trend, it is not unreasonable to project that in the near future there will be virtually universal access to the Internet in U.S. public schools. One caution, however, is the inequities in access between low and high minority enrollment schools and between high and low income schools. For instructional technologies to play a role in meeting the goal of science education for all students, these inequities must be eliminated.

WHAT IS THE POTENTIAL IMPACT OF INSTRUCTIONAL TECHNOLOGIES ON K-12 SCIENCE?

The classroom scenario that opened this paper illustrated two general types of applications of technology—those technologies that serve to provide students with access to resources beyond the walls of their classroom and those technologies that extend human capabilities. The next section will discuss this two general applications under the headings "The Global Classroom" and "The Technologically Enhanced Classroom."

The Global Classroom. The Internet has the capability to bring the world into the classroom and transport students to places undreamed of. As the previous discussion has shown, it is not an impossible dream. Access to the Internet is growing at an incredible rate with the national goal of every classroom being connected by the year 2000.

The Internet provides students with a vast array of resources, including original research documents, reference materials, and databases. Students can get help with homework, communicate with others from around the world, download satellite images, or develop their own web page, all from their classroom (or home) computer.

As vast and wonderful a resource as the Internet is, that very vastness can be a problem. As reported in *Science* in July 1999 (page 295), there are about 3 million servers hosting 800 accessible web pages. Unfortunately, the eleven most commonly used search engines are combined only able to access about 42% of the web and for the individual search engines, the coverage ranges from 16% to 2.2%.

Certainly schools are making strides in monitoring and controlling student access to web sites that are objectionable. Less progress has been made in monitoring the accuracy and age appropriateness of web sites. Unlike print materials, which generally go through some degree of peer review and whose availability can more easily be controlled, the world wide web is virtually open to anyone with a computer, a modem and the access to a server. How can teachers make effective use of the array of information available on the Internet that seems to be expanding at an exponential rate? How can teachers monitor the accuracy and age appropriateness of the web sites that their students are accessing?

These were questions that troubled the National Science Teachers Association (NSTA). In addition, teachers and textbook publishers bemoaned the fact that, with the rapid advances in science, textbooks were out of date as soon as they left the presses. Thus was born *sci*LINKS[2], an innovative project that links textbooks and the Internet. NSTA places *sci*LINKS symbols into textbooks at key topic areas. By keying in a code number, students, teachers or parents can access a relevant, age appropriate web site that has been selected by a panel of science educators. Although the information in the textbook may be static, *sci*LINKS has the ability to continually update the web site to reflect new information. According to NSTA Executive Director, Gerry Wheeler, "*sci*LINKS has the power to make the ever-growing Internet a manageable, useful tool for the teacher. It shortcuts the path to the teacher and to the learner and provides easy access to the latest information and technology. In fact, when researchers recently found liquid water in a meteorite that fell on Texas, we had information about it in *sci*LINKS the next day." (NSTA, 1999)

The Internet provides the opportunity for students to collaborate across distances. That collaboration can be with scientists, community members, parents, or with other students. One of the pioneers in this was TERC in Cambridge, Massachusetts and their collaboration with the National Geographic Society in developing the KidsNetwork[3] which offers elementary and middle grade students an opportunity to study real-world issues. Research teams of students, representing geographically diverse areas, collect data and share information with each other on the Internet. Participating scientists review the data and help students make interpretations.

Another exciting collaborative project is the GLOBE (Global Learning and Observation to Benefit the Environment) program[4]. GLOBE currently involves over 7,000 schools in more than 80 countries. Students make environmental observations near their schools and report those data through the Internet. Scientists use the data collected for their own research and share their findings with the students.

Negroponte and colleagues (1997) emphasize the value of global collaboration in creating a learning revolution. “Global connectedness can enable new 'knowledge-building communities' in which children (and adults) around the globe collaborate on projects and learn from one another.”

The global classroom also opens doors to other student opportunities including virtual field trips, access to informal science centers and virtual science fairs.

Imagine traveling to the bottom of the Atlantic in search of the wreck of the RMS Titanic. The JASON Project[5], under the leadership of explorer and oceanographer Dr. Robert Ballard, has been a pioneer in engaging students in virtual field trips. This year students will be traveling from NOAA's Aquarius Underwater Laboratory in the Florida Keys to NASA's International Space Station. Another web site, The Virtual Field Trip Site[6] is dedicated to providing teachers with access to information and pictures from areas and events that they might not be able to access, such as deserts, hurricanes, oceans, salt marshes, tornadoes, and volcanoes.

Informal science centers[7] (such as zoos, museums, nature centers, and aquariums) provide a wealth of resources to support the science classroom. However, in the past, access has been limited because of travel expenses or time limitations. The Internet lets students learn about the work of Benjamin Franklin at the Franklin Institute's[8] site in Philadelphia or participate in science experiments online from the Exploratorium[9] in San Francisco.

Virtual science fairs allow students to communicate their results to a world-wide audience. Negroponte and colleagues (1997) addressed the importance of students being able to express themselves directly. "New media will enable children to relate their own stories and ideas—and relate them to a much broader and more diverse audience—rather than having adults do the talking for them." The Cyber-Fair[10] sponsored by Mankato, MN Schools allows students in grades 3 through 6 to share their projects on the Internet. Some other virtual science fairs include: Brentwood School's (Los Angeles, CA) 1997 Virtual Science Fair[11] in which projects competing in the school-wide science fair had no printed reports or display; and CyberSpace Middle School[12], sponsored by Florida State University Supercomputer Computations Research Institute.

The Future of the Global Classroom. Given the pervasiveness of internet access currently available in the schools and projected into the near future, it is hard to imagine that the global classroom won't have a profound influence on science teaching and learning. Whether keeping up to date with the very latest developments, accessing real-time data, collaborating with others across the world, participating in experiences in other parts of the world, or communicating with a world-wide audience, the Internet provides the opportunity to bring the world into the classroom and the students into the world. In Learning with Technology (Dede, 1998) the 1998 Year Book of the Association for Supervision and Curriculum Development (ASCD), Kozma and Schank (1998) present a scenario of the connected classroom of the 21st century. They conclude:

> "Connections between school and work will allow students to learn in the context of real-life problems and will allow teachers to draw on the resources of other teachers, a range of professional development providers, and technical and business experts. Connections among schools, homes, and the rest of the community will enable students to relate what is happening in the world outside to what is happening in school, will allow teachers to coordinate formal education with informal learning, and will allow the community to reintegrate education into daily life." (page 5)

The Technologically Enhanced Classroom. In the early days of technology (10 to 15 years ago), there was much debate that technology would replace the teacher. This debate seems to have quieted as new technologies have demonstrated their ability to provide teachers with the time and opportunity to do what teachers do best -- provide human interaction. As Robert Tinker writes (1997), "There is no 'teacher proof' technology that can replace the thoughtful attention and educational guidance provided by an experienced teacher."

Technologies have provided incredible resources for teachers. The CD-ROM allows a teacher to have an entire encyclopedia or the latest census data in the classroom accessible at the click of a mouse. Laser videodiscs can store tens of thousands of images on a disk the size of an LP album or provide motion sequences that can be accessed by frame number. The advent of DVD technologies further expands the access of teachers to quality video resources at a reasonable price.

Robotics provides an opportunity for students to combine technology and science in a real-world application. With the availability of materials such as the LEGOdacto RoboLab[13], elementary school children can design and build robots. The FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition[14] provides an opportunity for teams of high school students to work with researchers in the design and construction of a robot. The teams compete in a task to test their robot design.

Laboratory interface devices extend the capability of the laboratory by making the computer another piece of laboratory equipment. Increasingly, new laboratories are being designed to fully integrate computers into the physical setting of the lab. The early pioneers of laboratory interface devices included light and temperature probes. Today's microcomputer-based laboratories (MBLs) provide a wide range of probes including, pressure, EKG, alpha waves, heart monitors, conductivity, sound, and motion detectors, just to name a few. These probes, along with the supporting software, allow students to collect, display, and analyze vast quantities of data over time periods ranging from seconds to days.

The Concord Consortium[15] is engaged in an innovative project, Science Learning in Context[16], to develop hardware, software, and curriculum material that use portable, networked, hand-held computers in student field projects. It is expected that these devices will allow students to keep digital journals in the field, to collect field data and consolidate those data with other students, as well as to develop models related to the data. According to Concord Consortium (1997), "using this approach, the researchers expect student inquiry to be more efficient, students investigations will be more expert, the resulting knowledge will be less inert, and many new topics will be amenable to student investigation."

Other advances provide software applications which allow students the opportunity to simulate and model real world events, such as Model-It (Krajcik, Soloway, Blumenfeld, and Marx, 1998) or to explore fundamental concepts in science such as genetics with GenScope[17]. These are just two examples of what is a large number of outstanding computer applications to support science teaching and learning.

The Future of the Technologically Enhanced Classroom? The future of the technologically enhanced classroom must be guided by two principles: access and quality. Access must keep in mind the kinds of hardware available to teachers. Programs that require wide band width or extensive memory may not be practical with the hardware available in schools. Hardware which is only affordable by wealthy schools will further exacerbate the inequities between low and high income schools. Future technologies need to support the premise of science for all students. Additionally, future technologies must be of a high quality. Technology should not be used for technology's sake. The appropriate role for technology is to promote learning in ways that could not happen or could not happen as efficiently without the technology. Teachers play an important role in demanding that suppliers of technology provide materials that are accurate in content and pedagogically sound in design.

How will technology support teachers? Technology will help teachers to do what they do best—meet the human needs of learners. Technology will reduce isolation by providing teachers opportunities to collaborate with colleagues around the world. Already the internet is a treasure house of lesson plans and instructional materials. Technology will also allow teachers to meet the needs of diverse learners. Currently most teachers have from 20 to 30 students in their class, all having different personalities, learning styles, capabilities, interests and motivations. The individualization available from technology, and the ability to manage diverse learners working on different projects and at various rates is one of the great promises of instructional technology. Technology will also allow teachers to communicate more effectively with parents. With the increase in home computers, parents can truly become a part of their children's learning through collaborative learning, access to information about their students projects and assignments, and through frequent email communications with teachers. By making parents and the home partners in learning, the effective learning time is virtually doubled.

It is important that professional educators continue to be actively involved in the conceptualization and development of new technologies for the science classroom. It is that perspective of understanding the development of children that is critical to making technologies useful. Furthermore, it is important that new technologies be aligned with the principles of the National Science Education Standards so that they are an integral part of the curriculum. Finally, it is important that new technologies support collaboration rather than isolation.

The sciences are a natural place for the integration of instructional technologies to improve teaching and learning. These technologies have the capability to potential for expanding the resources of the science classroom beyond imagination. Will we see the day in which instructional technologies are as invaluable to the science teacher as the beaker, balance, and bunsen burner are today? I believe the answer is "YES".

ENDNOTES

[1]For more information about the Telecommunications Act and the E-rate program see: http://www.sl.universalservice.org
[2]For more information about *sci*LINKS, see: http://www.nsta.org.scilinks
[3]For more information about KidsNetwork, see: http://www.terc.edu/byterc/ngs.html
[4]For more information about the GLOBE Program, see: http://globe.fsl.noaa.gov
[5]For more information about the JASON Project, see: http://www.jasonproject.org
[6]For more information about the Virtual Field Trip Site, see: http://www. Field-guide.com
[7] An excellent compilation of hands-on science centers from around the world is available at http://www.cs.cmu.edu/afs/cs/usr/mwm/www/sci.html.
[8]For more information about the Franklin Institute, see: http://sln.fi.edu
[9]For more information about the Exploratorium, see: http://www.exploratorium.edu
[10]For more information about the CyberFair, see: http://www.isd77.k12.mn.us/resources/cf/SciProjIntro.html
[11]For more information about Brentwood School's Virtual Science Fair, see: http://www.csun.edu/~lg48405/virtual/virtual_science_fair.html
[12]For more information about CyberSpace Middle School see: http://www.scri.fsu.edu/~dennisl/CMS/sf/sf.html
[13]For more information about RoboLab, see: http://www.lego.dk/dacta/robolab/defaultjava.htm
[14]For more information about FIRST Robotics Competition, see: http://www.usfirst.org/
[15]For more information about the Concord Consortium, see: http://www.concord.org/
[16]For more information about Science Learning in Context, see: http://slic.concord.org/
[17]For more information about GenScope, see http://genscope.concord.org/.

NOTE: An excellent review of research is found in Berger, C. F, Lu, C. R., Belzer, S. J. & Voss, B. E. (1994). Research on the uses of technology in science education. In D. L. Gabel (Ed.), Handbook of research on science teaching and learning, (pp. 466-490). New York: MacMillan.

REFERENCES

American Association for the Advancement of Science, Project 2061 (1993). Benchmarks for science literacy. New York, NY: Oxford University Press.

Dede, C. (Ed.). (1998). Learning with technology. Alexandria, VA: Association for Supervision and Curriculum Development.

Kozma, R. & Shank, P. (1998). Connecting with the 21st century: Technology in support of educational reform. In C. Dede (Ed.), Learning with technology (pp. 3-27). Alexandria, VA: Association for Supervision and Curriculum Development.

Krajcik, J., Soloway, E., Blumenfeld, P. & Marx, R. (1998). Scaffolding technology tools to promote teaching and learning in science. In C. Dede (Ed.), Learning with technology (pp. 31-45). Alexandria, VA: Association for Supervision and Curriculum Development.

National Center for Educational Statistics (1998). Internet access in public schools and classrooms: 1994-98. http://nces.ed.gov/pubs99/quarterlyjul/3-elem-sec/3-esq12-h.html.

National Research Council (1996). National science education standards. Washington, DC: National Academy Press.

National Science Teachers Association (1999). National science teachers association chosen to demonstrate new textbook-internet initiative at national education summit. http://www.nsta.org/pressrel/scilinks2.htm.

Negroponte, N., Resnick, M., Cassell, J. (1997). Creating a learning revolution. http://www.education.unesco.org/unesco/educprog/lwf/doc/portfolio/opinion8.htm.

President's Committee of Advisors on Science and Technology, Panel on Educational Technology. (1997). Report to the President on the use of technology to strengthen K-12 education in the United States. http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/PCAST/k-12ed.html.

Rakow, S. J. (Ed.) (1998). NSTA pathways to the National Science Education Standards: Middle school edition. Arlington, VA: National Science Teachers Association.

Search engines fall short (1999, July 16). Science, 285, 295.

Tinker, R. (1997, Spring). Netcourses reform education using the power of the internet. Newsletter, The Concord Consortium. http://www.concord.org/library/1997spring/netcoursesreform.html