Teaching Science in the 21st Century

Jack Rhoton and Patricia Shane, Editors

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Foreword

JoAnne Vasquez

Alice came to a fork in the road. "Which road do I take?" she asked.
"Where do you want to go?" responded the Cheshire cat.
"I don't know," Alice answered.
"Then," said the cat, "it doesn't matter."
~Lewis Carroll, Alice in Wonderland

Science leaders throughout the country are looking for direction and wanting to know which road to take. This book of compiled issues and trends in science teaching and learning is the insightful contributions of leading science educators from across the country. It will begin to provide the much needed direction and insight.

Not since the Soviet Union's launch of the Sputnik satellite—48 years ago—has the need to improve science education in America been as clear and as urgent as it is today. America's competitive edge in the global economy, its strength and versatility all depend on an education system capable of producing a steady supply of young people well prepared in science and mathematics.

In the face of many converging trends, efforts to reform and strengthen science education have been largely piecemeal and unfocused, yielding only modest gains. For the past few years, conversations about educational standards, classroom practice, measurable achievement, and teacher quality have linked the phrases *No Child Left Behind* and *scientific research*. What do these conversations mean, and how might they affect people directly involved in science education? This book will help shed light on some of these topics and provide a starting place for science educators and administrators to focus on the future of science in our nation's classrooms.

By 2007–2008 all schools will be testing science. Will science become another "data-driven" reform? Will we have teachers teaching a garbage-in-garbage-out approach just to make certain their students pass the test? Will good science teaching become only for the very elite students as our rural and urban communities struggle to hold onto qualified science teachers, who too often flee to the burbs for better working conditions and wages? The future is not ours to predict. We do know, however, that, unless there are drastic changes within the nation's science classrooms, we will be raising a generation of students who have had their curiosity defused. And they will not know how to think critically and will not become the scientifically literate citizens we need.

True, we face an uncertain future in science education, but we know that knowledge is power. This book will provide the resources to give us that knowledge. On behalf of the National Science Education Leadership Association (NSELA), I am very grateful for the insight, leadership, and editing by Jack Rhoton and Patricia Shane. These two dedicated science educators have once again shed light on the critical issues facing all science educators.

JoAnne Vasquez, PhD
NSELA President, 2005–2006

Preface

As we move deeper into the 21st century, local, state, and national reports continue to remind us that standards, assessment, and accountability are common public policy concerns. They are, in fact, driving much of our effort as we strive to improve science education at all levels. These concerns originate and are embedded in research—as well as in the politics and economics of education, which include unparalleled public spending for education and increasing concern for our knowledge economy and the rapidly evolving competitive world. Implicit in these concerns are a multitude of issues ranging from how students learn science to building science partnerships and collaboration to the ramifications of the federal No Child Left Behind legislation. Even though opinions vary on how to approach the challenges in education, the mandate for establishing an accounting system for the outcomes of schooling for all students has never been clearer.

With the challenges in mind, this book addresses issues and outlines the practical approaches needed to lay the foundation upon which science teachers and science educators—at all levels—can work together to build effective science programs. The book shares the research, ideas, insights, and experiences of individuals ranging from science supervisors to university personnel to those who work for agencies representing science education. The authors discuss how to contribute to the success of school science and how to develop a culture that allows and encourages science leaders to continually improve their science programs.

The 21 chapters in *Teaching Science in the 21st Century* are organized into five major sections. This organization places each chapter within a general theme. The intent is not to provide an exhaustive coverage of each section, but rather to present a stimulating collection of essays on relevant issues. Those major themes are

Within the Science Classroom: The science classroom is a dynamic environment in which students have the freedom to explore and to question. As students learn, they share what they have learned with one another, and they connect that new knowledge to their existing knowledge of the world. We introduce this theme in "The Impact of Technology on the 21st Century Classroom." Next we consider the importance of a standards-based curriculum, planning and assessing science instruction and student learning, planning science experiences for diverse student populations, and how to get classroom teachers engaged in research.

Professional Development: Implications for Science Teaching and Learning: Within the environment of increased teacher and student expectations, teacher professional development is cited frequently as a key strategy for improving student learning. This theme emerges in four chapters that examine the effectiveness of high-stakes accountability systems in bringing about improvements in professional development and student learning.

Leadership in Science Teaching and Learning: In today's complex educational system it almost goes without saying that, without effective leadership at all levels, substantive change to bring about improved science programs will not happen. Successful science programs involve many participants—among them teachers, administrators, and science supervisors—playing different roles. This premise is highlighted in four chapters. See in particular "Leadership in Science Education for the 21st Century."

Building Science Partnerships and Collaboration: A number of individuals and programs have demonstrated the potential for catalyzing widespread improvements in science education by building and nurturing appropriate partners. Their approaches can overcome formidable barriers. This theme emerges most fully in "The Importance of Partnerships in Science Education Reform." Other topics include the role of professional learning communities for strengthening the science program, the impact of the No Child Left Behind legislation on science education, and alternative certification.

Science of Learning Science: One of the aims of science education is to teach students about our accumulated knowledge of the natural world and to help them learn to use the methods, procedures, and reasoning processes that produced that knowledge. This approach is introduced in "The Psychology of Scientific Thinking: Implications for Science Teaching and Learning." This theme is discussed at length in three other chapters: "Brain Research: Implications for Teaching and Learning as the 21st[st] Century Begins," "How Do Students Learn Science," and "Research in Science Education."

In addition to the themes described above, the need to address local, state, and national standards is prominent throughout this publication.

Previous publications in this NSELA/NSTA series are *Issues in Science Education, Professional Development Planning and Design, Professional Development Leadership and the Diverse Learner,* and *Science Teacher Retention: Mentoring and Renewal.*

Teaching Science in the 21st Century captures the latest research, trends, and best practices in science education. Science teachers and science leaders can use it to vitalize their teaching and programs for improved student learning in science. This book, therefore, is directed at science teachers, science department chairs, principals, science supervisors, curriculum directors, superintendents, university personnel, policy makers, and any other individuals who have a stake in science education. The final determinant of success in our effort to improve science education will be measured by the quality of science programs delivered to our students and student outcomes.

Jack Rhoton
Patricia Shane

About the Editors

Jack Rhoton is an educator with more than 30 years of experience, covering every level of education from elementary through graduate school. He teaches science and science education courses to preservice and inservice science teachers at East Tennessee State University, where he is professor of science education. He is a researcher in K–12 science, especially in the area of professional development and its impact on science teaching and learning.

He has served as president of the National Science Education Leadership Association (NSELA), president of the Tennessee Academy of Science (TAS), and president of the Tennessee Science Teachers Association (TSTA). He is editor of the *Science Educator*, a publication of NSELA. He is also director of the Tennessee Junior Academy of Science (TJAS), and editor of the *TJAS Handbook and Proceedings*. He is widely published and has directed numerous science and technology grants.

He has received many honors, including the National Science Teachers Association (NSTA) Distinguished Service Award, the East Tennessee State University Distinguished Faculty Award, the TAS Outstanding Science Teacher Award, and the Tennessee Science Teachers Association Distinguished Educator of the Year Award.

Patricia Shane is the associate director of the Center for Mathematics and Science Education and is an associate professor of education at the University of North Carolina at Chapel Hill, where she teaches and provides professional development for mathematics and science teachers. She works closely with the UNC-Chapel Hill Pre-College Program, which recruits underrepresented groups into math and science fields.

She has been the project director for numerous grants, including more than 30 Eisenhower grants, and has received awards for service in science education, including the National Outstanding Science Supervisor Award from NSELA.

She was a science, mathematics, and reading /language arts coordinator at the system level and worked as a classroom teacher and guidance counselor at the school level.

She is serving as the immediate past-president of NSELA and is a past-president of the North Carolina Science Teachers Association and the North Carolina Science Leadership Association. She is a former district director for both NSELA and NSTA and is a current board member of NSELA.

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Many people worked with us to make this book a reality, and we would like to acknowledge their contribution. We would like to begin by thanking the staff at NSTA Press. Two of these exemplary professionals are Claire Reinburg and Betty Smith. We would also like to thank the many reviewers whose comments and suggestions were crucial in improving our work: James McLean, University of Alabama; Gerry Madrazo, Hawaii Department of Education; LaMoine Motz, Oakland County Schools, Michigan; and Martha Rhoton, Kingsport, Tennessee. No volume is any better than the manuscripts that are contributed to it; we appreciate the time and efforts of those whose work lies within the cover of this book.

We also want to thank and acknowledge the support, help, and suggestions of the NSELA board of directors: Nicola Micozzi, past president, for his suggestions and guidance in the early stages of the project, and executive director Peggy Holliday in the later stages of the project.

Finally, we would like to thank graduate assistant Rick Christian, East Tennessee State University, for his excellent work. Rick was instrumental in managing and wordprocessing the drafts of each manuscript.

CHAPTER

1

The Impact of Technology on the 21st Century Classroom

Karen E. Irving

Little doubt exists that advances in educational technology have already transformed the American classroom. Teachers in the 21st century enjoy access to information and resources that their predecessors could not imagine: state-of-the-art information available on the internet 24/7 on the most arcane subjects; still images and video of events from all over the world and even the universe, data sets on population growth, the environment, ocean currents, weather patterns, sporting events, and a myriad other topics that are available for student analysis and research in classroom lessons and projects; virtual field trips to remote locations such as Antarctica and geologic sites with active volcanoes or isolated island communities; sophisticated representations of atoms and molecules that can be enlarged, color coded, and presented in multiple model systems; animations of processes such as protein synthesis and salt dissolving in water; and virtual planetarium software packages that allow teachers to "turn off the Sun" during daylight hours to allow students to visualize the constellations that are present in the daytime sky.

This chapter explores how educational technology has changed and will continue to change the ways that teachers teach and students learn in classrooms of the 21st century.

The chapter begins with a description of how students can learn *from* computers with tutoring systems and drill and practice software. Next, it explores the use of primary sources available on the internet, data sets, CD-ROMS, video, and animations that offer examples of how students learn *with* (rather than from) technology. Probeware peripheral devices hooked to handheld calculators or computers, digital imaging systems such as cameras or microscopes, and multimedia presentation systems and software offer new ways to collect, analyze, and display data as well as to motivate students and engage their interest. Connected classrooms promise improved formative assessment as teachers monitor student learning more closely and tailor their lessons to individual students' needs. Communication applications such as e-mail, discussion boards, chat rooms, teleconferencing equipment, and course management systems all enhance the choices teachers have to strengthen writing and speaking skills with the opportunity to facilitate communication with members of the education community. Online learning communities connect learners and teachers in remote locations and extend the educational opportunities to a greater number of students. In this era of testing requirement mandated by the No Child Left Behind Act (NCLB) of 2001 (2002), states are motivated to find more efficient and effective ways to measure student achievement. Computer-based assessments present the advantage of immediate feedback allowing schools to analyze data, decide on policy, and implement new programs in a timely fashion. Lastly, this chapter explores how preservice and inservice teachers can best be prepared for the educational technology challenges of 21st century classrooms.

For years science teachers have been using technologies such as pH meters, balances, overhead projectors, and optical microscopes in the classroom. In this chapter, educational technology tools will be characterized as computer- and calculator-based electronic devices used to complete an educational task.

Learning *From* Technology

Information delivery is the paradigm that learning *from* technology supports. In this way of thinking about learning, the computer (or teacher) provides information to students, students read and understand the information, and achievement occurs when students provide an adequate response to questions regarding the content of this information. The student serves as a passive recipient of knowledge. The teacher/computer functions as an information delivery system (Reeves 1998).

The literature contains mixed messages regarding the effectiveness of computer-based instruction, computer-assisted instruction, intelligent learning systems, and other computer tutoring systems. In 1995, a study of

101 eighth-grade students in Turkey on the use of computer-aided instruction in chemistry classrooms followed a pre- and posttest control group design. The authors found that students using the computer-aided instructional program on the mole concept and chemical formulas showed significantly higher scores than the control group recitation sections (Yalçinalp et al. 1995). In another study, Chang analyzed 159 Earth science students' achievement in Taiwan in a pre- and posttest control group experiment and found significant difference between the groups (Chang 2001). Students in the problem-based computer-based instruction group scored generally higher on total items as well as on knowledge and comprehension-level items than did students in the control group.

On the other hand, Wenglinsky in his study on the relationship between educational technology and student achievement in mathematics attempted to identify whether computer use was making a difference in mathematics, which kind of computer use had what kind of effect, and how differences among students impacted achievement. After controlling for socioeconomic status, class size, and teacher characteristics, findings from this large quantitative study of 6,227 fourth-graders' and 7,146 eighth-graders' scores on the National Assessment of Educational Progress (NAEP) pointed to lower achievement in groups with higher levels of drill and practice exposure to computers and higher achievement with "higher order" applications of technology in the classroom. Wenglinsky concluded that how computers are used in the classroom represents an important factor in student achievement (Wenglinsky 1998).

Another large-scale longitudinal study with the West Virginia Basic Skills/Computer Education Program (BS/CE) focused on reading, language arts, and mathematics with a gradual phase-in of technology equipment and training from kindergarten through third grade. Using regression analysis, researchers concluded that the BS/CE program was responsible for a significant portion of the total variance in the measured student achievement (Mann 1999). Kulik analyzed more than 500 individual papers on the impact of computer-based instruction, computer-aided instruction, and other drill and practice software in a large meta-analytical study. The findings from this work showed 9 to 22 percentile gains for the computer-using groups over control groups (Kulik 1994). In addition to improvement in student achievement data, Kulik found that computer-based instruction decreased the amount of time needed for students to learn. Johnston, in another review of the research on the effectiveness of instructional technology, reported effect sizes for computer-based training ranging from 0.20 to 0.46 depending on the population and effect sizes for instructional technology in general ranging from 0.15 to 0.66 standard deviations. Of note is that all effect sizes reported favorable findings when compared to traditional teaching methods (Johnston 1995).

As these studies indicate, use of computers for drill and practice or as a student tutor has some support in the literature. In the data-driven current educational climate, school districts bent on increasing student achievement on standardized tests have taken note. These research reports, however, often add the caveat that, while large quantitative studies point to achievement gains, closer examination of the data shows that educational technology is less effective when learning objectives are unclear. Limiting educational technology integration to learning *from* technology overlooks many contributions that technology can make in 21st century classrooms.

Learning *With T*echnology

Knowledge construction is the paradigm for learning *with* technology. Rather than using technology as a source of information to pour into a passive learner, teachers employ technology to engage students with real-world problem solving, conceptual development, and critical thinking (Ringstaff and Kelley 2002). Student involvement with technology includes data collection, organization, analysis, and communication of results.

Use of primary data sources and interactive websites or software provides teachers with opportunities to engage students in inquiry-based science lessons from preschool to college level. These inquiry-based lessons enlist students in hands-on, minds-on science and encourage creative thinking and problem solving. Moore and Huber identified two types of internet sites as appropriate for inquiry-based lessons: 1) sites with data sets and interactive data visualization tools such as graphing programs, and 2) interactive sites that allow students to control virtual equipment and simulated resources (2001).

Data sets play a central role in the El Niño lesson in which students use monthly climate data (temperature and precipitation) from online databases to determine if the weather in their community varies from the norm during El Niño years. Students are introduced to spreadsheets, descriptive statistics (averages and standard deviations), and using graphing techniques to analyze the data (Bell et al. 2001). Other types of data sets that support inquiry lessons include athletic records, chemical element and periodic table data, and tidal information. The Center for Technology and Teacher Education at the University of Virginia offers a wealth of sample lessons for science and mathematics teachers that demonstrate how data sets can be integrated into lessons. These lessons can be accessed at *www.teacherlink.org*.

Interactive websites offer tools that students can use to learn about abstract science concepts. For example, students can change frequencies or wavelength and view the impact on wave formation and sounds at *www.mta.ca/faculty/science/physics/siren/Applets.html*; students can place seismometers and triangulate to locate the epicenter for an earthquake at *http://www.sciencecourseware.com/eec/Earthquake;* or students can view animations of water molecule visualizations to help them understand acids and bases at *www.johnkyrk.com/H2O.html*.

Software programs allow students to explore aspects of nature during the school day that would ordinarily be impossible. As part of an inquiry unit on Earth-Sun-Moon relationships, an Earth science teacher introduces her students to a virtual planetarium program.

Ida asks students to check their moon journals to recall where the Moon was located two days ago, where it was located yesterday, and where they expect to find the Moon today. Students share not only locations for Moon sightings from their journals, but also offer details about the shape and size of the Moon. Ida opens a virtual planetarium and shows images of the Moon's position and shape for the preceding few days to confirm students' observations. She asks, "If the Moon rises around 3:30 PM today, what time would it rise on Sunday? Will it rise earlier or later? What phase will the Moon have on Sunday?"

Ida continues the lesson: "Where do the stars go during the daylight hours?" Students consider possible answers, and agree that the stars must still be in the sky but that the power of the Sun's light makes it impossible to see them. Ida uses her virtual planetarium program to "turn off the Sun" and reveals the stars that students would see at Rural High School that day (Irving 2003).

In this lesson, Ida engages her students using both real data in their moon journals as well as virtual data from the planetarium software. Ida takes advantage of the unique features of this educational technology tool to allow her students to view the night sky during the daytime and to observe the apparent movement of heavenly bodies. She structures her lessons to engage students in learning by helping them formulate questions, collect evidence, make predictions, and apply the knowledge of the motion of the Moon to the motion of the stars.

Electronic data collection devices help teachers move the classroom to the field where students enjoy opportunities to use inquiry to develop questions based on their observations. Tools such as electronic probeware to collect pH, temperature, or oxygen levels link directly to handheld calculators or laptop computers and allow students to collect, record, and analyze data (Heflich et al. 2001). Middle and high school teachers in North Carolina engaged in a three-year technology-integrated project, Students as Scientists, developed by the University of North Carolina, Wilmington. The project included collecting and analyzing water samples from different sources in the Wilmington area and comparing their results to existing water-quality data available on the web (Comeaux and Huber 2001). Another example includes the use of motion detectors to help students understand kinematics graphing (Flores 2001; Friedler and McFarlane 1997).

Imaging devices such as digital cameras and digital microscopes offer additional opportunities for visualization in the science classroom. Students can observe the imbibation and germination of seeds using time lapse photography and digital microscopes. The transformation of a caterpillar into a chrysalis and the emergence of the butterfly captured in time lapse images as described below offer students windows into the subtle changes of nature that once could be learned about only in books (Bell and Bell 2002).

Ninth-grade biology students work in small groups at their low hexagonal laboratory stations finishing up an acid-base pH laboratory activity. Amy demonstrates the digital camera that students will use to record images during their inquiry projects. Students suggest recording close-up images of the plants at different stages of growth, images of the plants being treated with acid rain, images showing how the watering system functions to provide the plants with moisture, and images of the lighting system.

Amy next introduces the butterfly metamorphosis inquiry project. She asks her class to compare the experimental design of the acid rain project with this new observational project. In addition to the acid rain journal, students will record data daily in a butterfly journal. They will take pictures using a digital camera, record behavior using a digital microscope with both snapshot and video capture capability, make sketches by hand and record data describing the behavior of their caterpillars. Amy reviews the difference between observations and inferences with her students before she distributes the pillboxes with the caterpillars to her students (Irving 2003).

A different kind of educational technology use occurs in the connected classroom. Connected classroom technology refers to a networked system of personal computers or handheld devices specifically designed to be used in a classroom for interactive teaching and learning. These networked technologies include response systems, classroom communication systems, and newer systems included under the CATAALYST (classroom aggregation technology for activating and assessing learning and your students' thinking) name (Roschelle et al. 2004). Connected classroom systems offer opportunities for improved formative assessment through questioning and immediate feedback and allow teachers to tailor instruction to meet student needs (Black and Wiliam 1998; Fuchs and Fuchs 1986). Students beam answers anonymously to a receiving station and histograms of student answer choices are displayed. Data logs are archived for later analysis. Discourse that occurs in a safe environment through the public examination of problem solving and alternative conceptions helps students understand their role as critical listeners and thinkers in the classroom (Artzt and Yaloz-Femia 1999). In the connected classroom, teacher adaptive expertise allows formative assessment that can monitor students' incremental progress and keep them oriented on the path to deep conceptual understanding.

Improving Communication *With* Technology

The classroom, especially at the secondary level, has been described as a culture of isolation (Schlagal et al. 1996). Electronic communities for students and teachers offer a wealth of opportunities to break down barriers between people and provide settings for idea sharing and peer support (Bull et al. 1989; Casey 1994; Bodzin and Park 2002). Teachers use online communities, electronic bulletin boards, lesson plan banks, and listservs to stay connected to the larger educational community outside their classroom. Web-based forums promote reflective thinking for preservice science teachers in remote student teaching placements (Bodzin and Park 2002, 2000). In addition to supporting reflective practice, the public nature of the discourse encourages participants to respond thoughtfully (Yore 2001). Pairing inservice teachers and preservice students provides opportunities for improved teacher-student teacher communication, and also focuses on technology transfer from the university teacher education classrooms to inservice teachers (VanMetre 2000). The Teacher Institute for Curriculum Knowledge about the Integration of Technology (TICKIT) at Indiana University used asynchronous web-based conferencing for K–12 teachers from rural Indiana schools. Online debates focused participants around a particular content and resulted in greater content-based discussion than face-to-face forums (Bonk et al. 2002).

Teleconferencing technologies offer the opportunity for teachers and students in remote locations to have two-way audio and video communications. Cybermentoring with elementary and secondary schools has been explored in Washington State with telephones, e-mail, web design, and both low- and high-end videoconferencing systems. Recent projects pairing university faculty and students with K–12 students and teachers included fourth-grade science mentoring and ninth-grade Earth science curriculum planning projects (Maring et al. 2003). Online courses with high-end video conferencing are already in use for courses offered to Japanese students. Professors at Stanford, the University of California, Davis, and California State University, Hayward, offer pre-MBA courses to students in Tokyo's Hosei University. With complete multimedia capabilities, the videoconferencing system allows Japanese students to see live presentations of classes offered in California. Professors and students have access to a full palate of writing utensils to annotate and save slides from class lectures and discussions (Shinkai 2004).

The Rural Technology Initiative (RTI) sponsored by McREL (Mid-Continent Research for Education and Learning) provides quality training in technology integration for mathematics and science teachers and administrators in remote rural locations in Colorado, Kansas, Missouri, Nebraska, North Dakota, South Dakota, and Wyoming. This project provides training targeted at increasing student achievement through the use of technology and effective teaching strategies. Online courses save schools the travel, substitute, and hotel expenses usually associated with traditional professional development opportunities. Videoconferencing, an internet portal, and teleconferencing are part of the online delivery system for this professional development. Science teachers receive college credit in science technology integration to help teachers meet the NCLB highly qualified teacher requirements (REL Network 2004).

Course management systems have become more popular on college and university campuses as well as for schools in the K–12 sector. Although initially courseware companies suggested that these tools would help reach ‘distant’ students, the audience for courseware tools is mostly local students in traditional educational programs. Convenience for large numbers of resident students as well as off-campus adult students plays an important role in the use of course management systems. These applications allow professors to build course content, offer chat rooms for guided discourse, link to electronic resources on other websites, and manage course grades. Course management tasks such as planning, organizing, structuring, tracking, reporting, communication arrangements, and expectations were tracked by Nijhius and Collis in their study of 51 instructors’ use of web-based course management systems at the University of Twente, Netherlands, during one academic year (2003).

Assessment and Educational Technology

In this era of NCLB testing requirements, states are searching for more efficient and effective ways to determine student achievement. Computer-based assessments offer the advantage of immediate feedback, allowing schools to analyze data, decide on policy, and implement new programs in a timely fashion. Traditional testing formats often take weeks or months to score and return to schools. According to *Education Week’s* Technology Counts report in May 2003, 12 states and the District of Columbia are already using or piloting computerized exams. All except one of these programs are internet-based (Edwards 2003).

The demands of NCLB can be seen as either support for or hindrance to computerized testing. Although technology offers the potential for streamlined assessment and accountability options, schools need computers for students to take tests online. With budgets limiting school options, it seems unlikely that many school systems will be able to take advantage of this opportunity without an infusion of capital. The secure conditions required to limit opportunities for cheating on high-stakes tests represent another problem. Students across a state must take the test in a limited time and under the same conditions as all other students. The questions become: How many computers are needed, and can the connections needed to internet websites be guaranteed across the state at the same time? Equipment often varies from school to school, complicating the issue of fairness. If some students in a state take paper-and-pencil tests and others take computerized versions, is one group or the other advantaged? Do students with outdated computers suffer compared to their peers with more modern technology resources (Olson 2003)?

Although high-stakes testing raises many issues for educators, low-stakes diagnostic computerized testing offers many possibilities for improving student performance. The logic is that success on low-stakes tests will lead to improved performance on their high-stakes cousins. In addition to low-stakes individual classroom use of computer-based testing, many experts predict that most states and districts will use online test preparation programs to help raise student scores on high-stakes assessments. Twelve states already have computer-based practice exams available to help students prepare for state-mandated tests (Borja 2003).

Opportunities for special education students to fully participate in the classroom through the use of assistive technologies are the focus of research efforts in both the special education and educational technology communities (Rose 2001; Hitchcock et al. 2002). Inexpensive, efficient test delivery and rapid scoring as well as an opportunity to make state tests more accessible to special populations of students argue in favor of computerized testing programs. Special education students may serve as test populations as educators experiment with new technology-based assessment systems. In Indiana, electronic portfolios are used to measure the progress of students with disabilities. A videotape of oral reading ability collected annually provides a unique and highly individual view of a student's progress over a multiyear period (Goldstein 2003).

Other innovative programs in computerized assessment include Indiana's plan to create a deep online test item bank with each item linked to appropriate state standards and Oregon's efforts to produce an online writing assessment. Adaptive testing, where students are pitched questions from the computer test bank that are chosen based on performance on earlier items, provides useful diagnostic information for educators, but does not meet the demands of NCLB to assess each student against the grade-level standards set by the state. South Dakota developed an adaptive online testing program, but has made it voluntary for schools and has added a paper-and-pencil test to meet the requirements of the NCLB legislation (Olson 2003; Trotter 2003).

Preparing Teachers for the 21st Century Classroom

Professional science and education organizations have stated positions regarding the preparation of science teachers (AAAS 2002, 1998; ISTE 2002; NCATE 1997; NRC 2000; Willis and Mehlinger 1996). Common aspects of the recommendations offered for teacher preparation include a) providing skills training for educational technology in the context of science teaching; b) modeling appropriate uses of educational technology to teach science in preservice methods classes; c) providing opportunities for preservice teachers to practice using educational technology in science teaching; d) providing opportunities for preservice teachers to observe inservice teachers model educational technology use for science teaching; and e) providing opportunities for preservice science teachers to use educational technology during their student teaching experience.

The early literature regarding student teacher use of technology in secondary science teaching revealed that despite attempts to provide technology training for preservice science teachers, little transfer of this knowledge to their secondary classrooms occurred during their teaching (Barton 1993; McFarlane 1994; Kennedy 1996; Parkinson 1998; Byrum and Cashman 1993). Simply teaching novice teachers how to use technology proved insufficient preparation for them to integrate the same skills into their classroom teaching. Findings from recent research projects indicate that participants who complete a sustained technology-enriched preparation program report feeling adequately prepared to teach science using technology both during student teaching and during their first year in the classroom (McNall 2003; Irving 2003).

ePCK, electronic pedagogical content knowledge, includes the knowledge classroom teachers need in addition to the knowledge of their content domain, pedagogy, and curriculum in order to integrate educational technology successfully into their teaching. Shulman (1986) first described pedagogical content knowledge (PCK) as the teacher's knowledge of the best ways to teach particular concepts, which concepts are apt to cause confusion for students, common misconceptions for students in a particular domain, a wide variety of teaching strategies from which to select the best approach for a particular student group, and the most appropriate demonstrations, laboratory exercises, analogies, images, diagrams, problems, and explanations to make a subject transparent for students. Expert teachers not only have a deep conceptual understanding of the topics they teach, but they also understand why students are challenged when learning some topics and not others.

Two important aspects of ePCK for integrating technology into science teaching include being able to recognize the connection between the technology, the science content, and the pedagogy for a lesson, and being able to recognize how the technology can help students dispel or avoid misconceptions in a particular domain. As with science content, it is not enough to have a deep understanding of educational technology to be able to teach effectively using its tools. Teaching involves identifying the match between the learner's prior knowledge, how the new content fits with the already known, and the strategy the teacher chooses to present new topics. Teacher knowledge of educational technologies that offer compelling animations, interactive simulations, images, data sets, data collection and analysis tools, and communication tools that fit the curriculum topics for their science discipline is an important element of ePCK.

Not every domain in a science class will fit the use of educational technology equally well. Hands-on activities where students manipulate objects and create artifacts in the classroom offer compelling strategies for many science concepts. However, many concepts in science are abstract, complex, and invisible without the aid of special technologies, or too subtle for ordinary viewing in the classroom. Electronic technologies offer science teachers a host of powerful tools to help students visualize these concepts. ePCK knowledge involves the developing process of recognizing the parts of a science curriculum that would benefit from the use of educational technology tools to illuminate abstract or complex topics. Knowing about the technology, knowing how to use the technology, knowing how the technology fits the curriculum, knowing how the use of the technology contributes uniquely to the lesson and helps students avoid or dispel misconceptions regarding the content in a particular domain constitute important aspects of ePCK.

Teacher education programs face the dual burdens of constantly changing educational technology as well as a climate of rising expectations for technology use in teaching and learning. Despite these challenges, an excellent example of an integrated technology enrichment program is provided for student teachers at the University of Virginia (Bell and Hofer 2003; Cooper and Bull 1997).

In this program, students learn not only learn how to use educational technologies but also are encouraged and required to envision, plan, and implement lessons using technology with objectives clearly tied to the national and state standards. The sequential mode of instruction—from the introductory course focusing on word processing, e-mail, and networking—through an educational technology course with a science- and mathematics-specific syllabus followed by a year-long science methods class where educational technology is routinely modeled in appropriate and effective ways provides a sustained approach to technology integration. Students spend time identifying resources, learning how to use them, thinking about how they fit the curriculum objectives of their specific disciplines, designing lessons to include these technologies with a guiding framework provided by the Flick and Bell standards for effective and appropriate integration in science classrooms (Flick and Bell 2000), and finally reflecting on the successes and failures of their implementation efforts.

Conclusion

What are the messages to educators about the impact of educational technology in 21st century classrooms? Sweeping changes have occurred in the workplace where faxes, computer networks, e-mail, and teleconferencing alter the daily routines of modern people. Policy makers, business leaders, and parents urge educators to prepare students for the high-tech world of the contemporary community. School boards and superintendents have amassed impressive resources to wire and equip the school houses of America to allow students and teachers access to the powerful interactive technologies of the future. Not only will students in the 21st century learn *with* technology, but colleges of education have an obligation to help their preservice teachers learn about and implement educational technology in their teaching and learning.

An important message that can be gleaned from the research on educational technology in classrooms of the 21st century is that technology represents a means, not an end. Educators and policy makers recognize that in addition to infrastructure, maintenance, and reliability, an essential condition for success is that teachers must have *ePCK, electronic pedagogical content knowledge*. Teachers must know not only how to use the technology but also how to teach with technology in appropriate and effective ways. Technology alone does not improve instruction or student achievement; rather, technology works when it serves clear educational goals and is implemented in pedagogically sound ways.

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