Science Education Leadership

BEST PRACTICES FOR THE NEW CENTURY

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Edited by Jack Rhoton

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Foreword

Brenda Wojnowski
NSELA President 2009–10

The United States is at a critical juncture as many states, districts, and schools struggle to develop strategies and methodologies to prepare our students for life in this still relatively new century. We are well aware of the significant changes we, as educators, must make in our ways of thinking and doing in educating our populace, from preK education through career inservice. The need is critical; the structures and thought patterns which must be developed and implemented within our education system is the crux of the struggle. According to Tom Friedman, "the school, the state, the country that empowers, nurtures, enables imagination among its students and citizens, that's who's going to be the winner" (Pink 2008).

The Partnership for the 21st Century (2008) identifies the forward-thinking learning and innovation skills that are critical to students as (1) creativity and innovation skills, (2) critical thinking and problem-solving skills, and (3) communication and collaboration skills. To attain these skills, our students must be able to interact both with their immediate neighbors and with other students and potential workplace partners around the globe. We must develop mindsets that allow our students to understand and be sensitive to the intricacies of cultures that are very different from our own. At the same time, we must help our students to

develop the science/technology/engineering/ mathematics strengths that will allow the United States to prosper and thrive in the modern world.

The chapters within this volume address many of the issues that currently occupy education leaders who are working to address the skill sets needed for 21st-century success in a global community and marketplace. *Science Education Leadership* will aid leaders in guiding the teaching and learning occurring within our classrooms as well as the thoughts and policies being formulated within our state and federal departments of education. The work of 21st-century education is imperative—the timing of the guidance and planning is crucial.

The National Science Education Leadership Association is pleased to be a part of the infrastructure that stands in support of quality publications that will be used to improve education and inspire the future of young people throughout the United States and the world.

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Preface

Jack Rhoton

At no other time in the history of science education has the need for leadership been more important to ensure that all students in our nation's schools get the training they need to succeed. It has almost become a cliché to recognize that we live in the Information Age, an age that has mushroomed into the globalized knowledge economy. There is no doubt, however, that there is extensive support for the notion that science is vital for our economic competitiveness and for a science-literate public that can share in discussions—and make intelligent decisions regarding—science issues. In order to prepare students for success, we must instill in them the ability to constantly adapt through lifelong learning. Clearly we operate within a very complex educational system, and this will require strong science education leadership from a wide of array of individuals, businesses, organizations, and institutions.

Just as change is a permanent attribute of our time, leadership in science education needs to be continuously exercised with the ultimate goal of improving student learning. We all know that leadership takes on many forms, but a common theme in leadership is that leaders have vision. Leaders are able to develop a consensus around an idea, goals, and a course of action. They are able to mobilize people's commitment to improve. They

make it possible for others to do good work. However, different leaders take on different roles and may have different ways of clarifying a vision. For example, some science leaders may craft futuristic models of science education or examine the impact of brain research on the teaching and learning of science. Some leaders may be able to impact science education through policy initiatives, others through their writing, and still others by defending the integrity of science. Science teachers can also be leaders in their individual classrooms and schools.

The community of science education is made up of systems and subsystems, all of which consist of individuals and groups with different agendas and goals for improving science education. Science teachers, science educators, administrators, curriculum directors, university personnel, scientists, business and industry, Congress, and members of the current administration all have unique roles to play in advancing the support of science education. Science education leaders must know their constituents and be able to enlist people in a vision. Leaders must understand their needs, speak their language, and fashion a unity of purpose that enables constituents to share in a vision. These visions are played out in different ways. Not all in the science education community can or should be engaged in research, crafting curricular materials, developing technology programs, or providing professional development. We all have distinct talents, roles, and responsibilities. If we take action, we can turn our vision for a better tomorrow into initiatives that become actions that will make a difference for our students. Leadership is the conduit that can assemble the various components of science education reform efforts in ways that improve instruction and learning at all levels.

It is my belief that the central goal of science education should be to allow every student to achieve high levels of scientific literacy. Achieving this type of literacy for all students requires science education leadership from all constituent groups. Furthermore, all groups must communicate and work together toward clearly identified, mutually agreed upon objectives. Leadership must forge connections between the important components of the science education system, including national, state, and local science programs, as well as individual classroom practices such as teaching, curriculum design, and assessment. Collaboration will be required of science education leaders as they work in an increasingly complex educational environment.

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

The 18 chapters in *Science Education Leadership* 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:

The Science Education Challenge: Redefining Science Education Leadership for the 21st Century. Whether in the classroom, the curriculum office, or the boardroom, the science education leader has a desire to inspire others and pioneer changes that build stronger science education programs. Leaders are willing to relinquish familiar and commonly held practices and embrace change. We introduce this theme in "Looking Forward Into the 21st Century: Implications for the Science Leader." Next, we consider the leadership exhibited by business leaders and how they are investing resources and energy to target systemic reform initiatives in science education. This is followed by a look at the challenges that science leaders face as they develop ways to imbue upcoming generations with 21st-century workforce skills. The section concludes with a look at the many faces of leadership found in a complex educational environment.

The Role of School and District Science Leadership for Building Instructional Capacity. Strong science education leaders are needed to build and organize an infrastructure that supports deep learning for both teachers and students. Instructional leadership consists of actions that promote improved student learning not only in one's own classroom, or one's own school, but throughout an extended community. Therefore, science education leaders not only view instructional quality as a top priority,

they also encourage others around them to share this priority. Successful science programs involve many participants—among them teachers, principals, and science supervisors. This theme develops over four chapters that examine the impact of instructional leadership on instructional quality and student outcomes. See in particular, "Content Coverage and the Role of an Instructional Leader."

School and District Science Leadership: Rationale, Strategy, and Impact. Science education leaders can create a robust digital age educational community that supports the use of advanced technologies in the teaching and learning of science. This section begins by addressing the critical role of transformational leadership in the science education community for effective and appropriate infusion of educational technology as a fundamental component of K–12 education. This topic is followed by examples of leaders who foster inquiry-based learning and teaching in a variety of settings, including classrooms, local communities, schools and districts, college science classrooms, teacher preparation programs, and professional experiences. Other chapters in this section address teacher preparation, induction, and ongoing professional development as well as the role of graduate mobility in recruiting new teachers and developing new leaders.

School Improvement Processes and Practices: Professional Learning for Building Instructional Capacity. The role that professional learning communities have in improving and coordinating our efforts to establish higher expectations for students, improve instructional practices, and increase student achievement outcomes through a shared curriculum-focused vision is of inestimable value. This theme emerges most fully in "Professional Learning Communities: School Collaboration to Implement Science Education Reform." Other topics in this section include leading through collaboration, assessing assessment to inform science leadership, and professional development.

Leadership That Engages the Public in the Understanding of Science. This country places a high value on science and science teaching, and this content area is well established in the American school curriculum. Our nation invests a significant amount of resources in science education at all levels. We value science, because our society believes it is important for

preparing our students for the 21st-century workforce, preparing future scientists, and providing nonscientists with the science knowledge necessary to make informed decisions about issues affecting their everyday lives. However, the results of efforts to engage the general public in science have been mixed. For this reason, an argument is made that education and science education leaders should be prepared to communicate with the public, media, and decision makers to facilitate a better exchange of information between science professionals and society as a whole. These themes are highlighted in two chapters in this section: "Leadership for Public Understanding of Science" and "Science Communication and Public Engagement With Science."

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

Previous publications in this NSELA/NSTA series are *Issues in Science Education, Professional Development Planning and Design, Professional Development Leadership and the Diverse Learner, Science Teacher Retention: Mentoring and Renewal,* and *Science Teaching in the 21st Century*.

Science Education Leadership: Best Practices for the New Century captures the best thinking and best practices for science education leaders. Science educators can use it to vitalize their work. The book is directed at science teachers, science department chairs, principals, science supervisors, curriculum directors, superintendents, university personnel, policy makers, and any other individual who has a stake in science education. The final determinant of success in our effort to improve science education will be the degree to which we achieve high levels of scientific literacy for all citizens. The exercise of science education leadership is of the utmost importance if we are to achieve this goal.

Acknowledgments

Jack Rhoton

I wish to express my sincere appreciation to the individuals who made this publication possible. In particular I would like to thank the authors. In all cases, they addressed the theme, submitted manuscripts in a timely fashion and responded to reviewer recommendations. No volume is any better than the manuscripts that are contributed to it; we appreciate the time and effort of those whose work lies within the cover of this book.

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About the Editor

Jack Rhoton has devoted his entire career to teaching, writing and advocating for the support and advancement of science education at all levels, K–16. He began his career as a high school science teacher and subsequently served as a K–12 science supervisor for fourteen years. He joined East Tennessee State University as professor of science education in 1987 where he is currently serving as executive director of the ETSU Center of Excellence in Mathematics and Science Education. He has served as president of the National Science Education Leadership Association (NSELA), Tennessee Academy of Science (TAS), and the Tennessee Science Teachers Association (TSTA). Among his many publications are several NSTA edited books, including *Teaching Science in the 21st Century*. Rhoton earned a bachelors of science in biology from East Tennessee State University, masters in biology from Old Dominion University, masters in science education from the University of Virginia and a doctorate in science education from the University of Tennessee. He has received many honors, including the National Science Teachers Association Distinguished Service Award.

Chapter 3

A New Challenge for Science Education Leaders

Developing 21st-Century Workforce Skills

Rodger W. Bybee

The dawn of the 21st century shed light on a variety of new challenges for the United States in general and science education in particular. Popular books such a Thomas Friedman's *Hot, Flat, and Crowded: Why We Need A Green Revolution–And How It Can Renew America* (2008) and Fareed Zakaria's *The Post-American World* (2008) sent powerful signals that all was not well, and now is the time for change. While Thomas Friedman directs attention to the environmental crisis, economic instability, and population problems, the theme of Zakaria's book can be expressed as "the rise of the rest." That is, this era is less about the decline of America and more about the rates and directions of economic growth of other countries. Since these books were published, the global economy has experienced the worst decline since the Great Depression.

Few question the observation that the United States is losing its competitive edge in the global economy. Central to the global economy is scientific progress and technological innovation. The United States needs a workforce with higher levels of scientific and technological literacy in general and thus there is a need for talented individuals to enter scientific and engineering careers.

With these ideas in mind, I brought up the need for 21st-century skills and abilities as learning outcomes during a recent conversation with several science education leaders. The colleagues indicated that many were talking about 21st-century skills, but few were making concrete the abstract nature of this goal. Actually, they had much shorter and more dismissive statements. Probing their response, I found that they generally agreed with the goal, but they thought there was a need to describe specific skills and indicate how those skills might be implemented in school programs and classroom practices—without changing or diminishing the primary goal of learning science content. Of course, I told them this was possible. I did this without noting that the primary goal of science education was to prepare citizens for life and work, not exclusively for careers in science and engineering. They countered with a request for concrete, practical examples of the 21st-century skills and ideas for school science programs and classroom practices that would be appropriate responses. This chapter is my response to that request.

Business and Industry Signal the Problem

In September 2005, with support from the Office of Science Education at the National Institute of Health, Biological Sciences Curriculum Study (BSCS) compiled key recommendations from 20 major reports from business, industry, government agencies, and associated groups (see Table 1). The process synthesized recommendations for K–12 science and technology education. The panel directed attention to science and technology education, because the potential of these disciplines to contribute positively to the emerging goal of developing a 21st-century workforce had not been fully recognized. The resulting report was published in January 2007 under the title, *A Decade of Action: Sustaining Global Competitiveness* (BSCS 2007).

One finding of this effort was disturbing. Almost without exception, the various examined reports mentioned the critical role of science and technology in the economy, but they seldom addressed the topic of science and technology education specifically; literacy and mathematics were the leading disciplines. Most would agree that education has to account for increased reading and mathematics achievement, but science and technology education also must be seen as fundamental to achieving workforce competencies, especially when those competencies include critical thinking,

Table 1. Twenty Contemporary Reports Reviewed

Achieve, Inc. 2005. *Rising to the challenge: Are high school graduates prepared for college and work? A study of recent high school graduates, college instructors, and employers.* Washington, DC: Peter D. Hart Research Associates.

Achieve, Inc., and National Governors Association. 2005. *An action agenda for improving America's high schools.* Washington, DC: Achieve.

American Electronics Association (AeA). 2005. *Losing the competitive advantage? The challenge for science and technology in the United States.* Washington, DC: AeA.

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Barton, P. E. 2002. *Meeting the need for scientists, engineers, and an educated citizenry in a technological society.* Princeton, NJ: Educational Testing Service.

Business-Higher Education Forum (BHEF). 2003. *Building a nation of learners: The need for changes in teaching and learning to meet global challenges.* Washington, DC: BHEF.

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Coble, C., and M. Allen. 2005. *Keeping America competitive: Five strategies to improve mathematics and science education.* Denver, CO: Education Commission of the States.

Committee for Economic Development (CED). 2003. *Learning for the future: Changing the culture of math and science education to ensure a competitive workforce.* Washington, DC: CED.

Council of Chief State School Officers (CCSSO). 2006. *Mathematics and science education task force: Policy statement executive summary.* Washington, DC: CCSSO.

(continued on next page)

Table 1. Twenty Contemporary Reports Reviewed (continued)

Donohue, T. J. 2006. *The state of American business 2006*. Washington, DC: U.S. Chamber of Commerce.

National Academies. 2005. *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academy Press.

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Roberts, G. 2002. *SET for success: The supply of people with science, technology, engineering and mathematics skills.* London, UK: Institute for Employment Studies.

Secretary's Commission on Achieving Necessary Skills. 1998. *Learning a living: A blueprint for high performance*. Washington, DC: U.S. Department of Labor.

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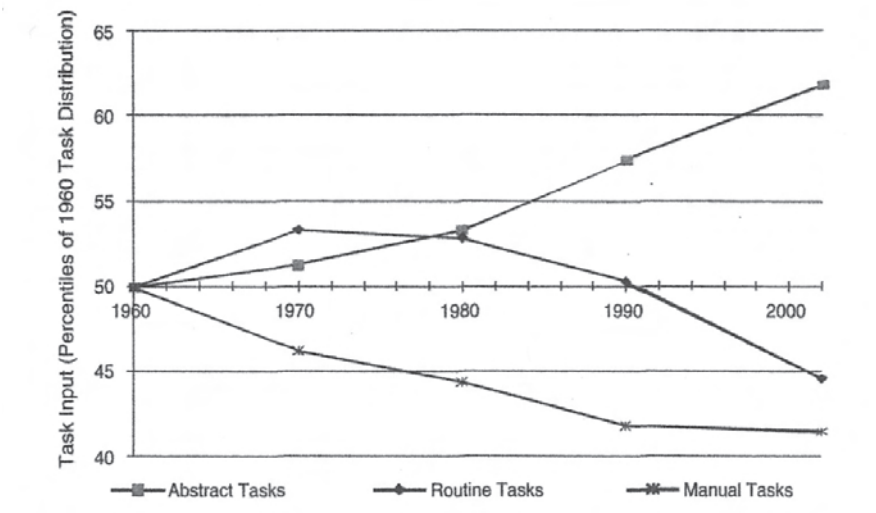
solving semi-structured problems, and reasoning: much like the abilities of scientific inquiry and technological design. Still, there was a need to move from broad, policy-level recommendations to more concrete and practical statements of skills and abilities.

Clarifying Future Skill Demands

I begin this section with one example that both illustrates skill demands and underscores the need for an emphasis on what is generally referred to as inquiry-oriented science. Figure 1 illustrates changes in skill requirements in the U.S. job market from 1960 to the early years of the 21st century. Note that the steepest decline during recent decades took place in routine tasks (mental tasks that can now be completed by computers). In contrast, jobs requiring high levels of abstract tasks—nonroutine analytic problem-solving—have increased. This also includes interactions with others, such as with group problem solving and interpersonal communication. One other feature of this chart that should be noted is that manual tasks have also declined.

Figure 1. Trends in Job Tasks



SOURCE: AUTOR, D. 2007. *TECHNOLOGICAL CHANGE AND JOB POLARIZATION: IMPLICATIONS FOR SKILL DEMAND AND WAGE INEQUALITY*. PRESENTATION AT THE NATIONAL ACADEMIES WORKSHOP ON RESEARCH EVIDENCE RELATED TO FUTURE SKILL DEMANDS.

What does this mean? If students in science classes only memorize and reproduce scientific knowledge, they are being prepared for jobs that are fewer in number and lower in skills and wages. In contrast, if students have experience solving problems, working in groups, and communicating conclusions using evidence, they are developing the knowledge, skills, and abilities to participate in this century's economy. Let's look more closely at details of 21st-century skills.

In 2007, the National Academies held two workshops that identified five broad skills that accommodated a range of jobs from low-skill, low-wage service to high-wage, high-skill professional work. Individuals develop these broad skills within contexts such as science and technology

Table 2. Examples of 21st-Century Skills

Research indicates that individuals learn and apply broad 21st-century skills within the context of specific bodies of knowledge (National Research Council 2008a, 2000; Levy and Murnane 2004). At work, development of these skills is intertwined with development of technical job content knowledge. Similarly, in science education, students may develop cognitive skills while engaged in study of specific science topics and concepts.

Adaptability: The ability and willingness to cope with uncertain, new, and rapidly changing conditions on the job, including responding effectively to emergencies or crisis situations and learning new tasks, technologies, and procedures. Adaptability also includes handling work stress; adapting to different personalities, communication styles, and cultures; and physical adaptability to various indoor or outdoor work environments (Houston 2007; Pulakos, et al. 2000).

Complex Communications/Social Skills: Skills in processing and interpreting both verbal and nonverbal information from others in order to respond appropriately. A skilled communicator is able to select key pieces of a complex idea to express in words, sounds, and images, in order to build shared understanding (Levy and Murnane 2004). Skilled communicators negotiate positive outcomes with customers, subordinates, and superiors through social perceptiveness, persuasion, negotiation, instruction, and service orientation (Peterson et al. 1999).

programs, a well as other settings (NRC 2008a, 2000; Levy and Murnane 2004). The skills identified, based on the National Academies workshops, are displayed in Table 2.

A review of Table 2 reveals a mixture of cognitive abilities, social skills, personal motivation, conceptual knowledge, and problem-solving competency. Although diverse, this knowledge—and many of these skills and abilities—can be developed in inquiry-oriented science classrooms. That said, it should be made clear that science programs cannot, and probably should not, assume complete responsibility for developing *all* 21st-century skills. Even so, inquiry-oriented science classrooms have the opportunity to make a substantial contribution.

Table 2. Examples of 21st-Century Skills (continued)

Nonroutine Problem Solving: A skilled problem solver uses expert thinking to examine a broad span of information, recognize patterns, and narrow the information to reach a diagnosis of the problem. Moving beyond diagnosis to a solution requires knowledge of how the information is linked conceptually and involves metacognition—the ability to reflect on whether a problem-solving strategy is working and to switch to another strategy if the current strategy isn't working (Levy and Murnane 2004). It includes having creativity to generate new and innovative solutions, integrating seemingly unrelated information; and entertaining possibilities others may miss (Houston 2007).

Self-management/Self-development: Self-management skills include the ability to work remotely, in virtual teams; to work autonomously; and to be self-motivating and self-monitoring. One aspect of self-management is the willingness and ability to acquire new information and skills related to work (Houston 2007).

Systems Thinking: The ability to understand how an entire system works, and how an action, change, or malfunction in one part of the system affects the rest of the system; adopting a "big picture" perspective on work (Houston 2007). It includes judgment and decision-making; systems analysis; and systems evaluation as well as abstract reasoning about how the different elements of a work process interact (Peterson et al. 1999).

Adapting 21st-Century Skills for Science Education Programs

This section provides an introductory description of the five skills (see Table 3, pp. 42-43, for specific examples) in the context of school science programs. Terms, strategies, and contexts that are used within the science education community will be used for descriptions of the skills and abilities. This discussion also presents connections to the *National Science Education Standards* (NRC 1996).

Adaptability

Science programs will provide learners with experiences that require coping with new approaches to investigations, analyzing less-than-clear data, using new tools and techniques to make observations, and collecting and analyzing data. Programs will include opportunities to work individually and in groups on science activities, investigations, laboratories, and field studies.

Specific examples from the National Science Education Standards (NSES) include

- Use appropriate tools and equipment to gather, analyze, and interpret data.
- Design and conduct a scientific investigation.

Complex Communication/Social Skills

Programs with varied learning experiences, including laboratories and investigations, will require students to process and interpret information and data from a variety of sources. Learners would have to select appropriate evidence and use it to communicate an explanation. Science programs would include group work that culminates with the use of evidence to formulate a conclusion or recommendation.

Specific examples from the NSES include

- Design and conduct scientific investigations (with a group).
- Communicate scientific procedures and explanations, as well as defend a scientific argument.
- Use technology and mathematics to improve investigations and communications.

Nonroutine Problem Solving

Science programs will require learners to apply knowledge to scientific questions and technological problems, identify the scientific components of a contemporary issue, and use reasoning to link evidence to an explanation. In the process of scientific investigations, learners will be required to reflect on the adequacy of an answer to a question or solution to a problem. Students may be required to think of another investigation or another way to gather data and connect those data with the extant body of scientific knowledge.

Specific examples from the NSES include

- Identify questions that can be answered through scientific investigations.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationship between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.

Self-Management/Self-Development

Programs will include opportunities for students to work on scientific investigations alone and as a group. These investigations would include full inquiries and may require learners to acquire new knowledge and develop new skills as they pursue answers to questions or solutions to problems.

Specific examples from the NSES include

- Design and conduct a scientific investigation.
- Use appropriate tools and techniques to gather, analyze, and interpret data.

Systems Thinking

School science programs would include the introduction and applications of systems thinking in the context of life, Earth, and physical science as well as multidisciplinary problems in personal and social perspectives. Learners would be required to realize the limits to investigations of systems, describe components, flow of resources, changes in systems and subsystems, and reasoning about interactions at the interface between systems.

Specific examples from the NSES include

- Identify questions that can be answered through scientific investigations.

- Design and conduct a scientific investigation.
- Think critically and logically to make the relationship between evidence and explanation.

Table 3 summarizes essential features of the skills and provides examples for school science programs.

Challenges for Curriculum, Instruction, and Assessment

Addressing the need to develop 21st-century workforce skills will require students to have experience with activities, investigations, and experiments. In a word, the curriculum needs to be *inquiry-oriented*. This orientation seems obvious, but it must be emphasized. Science education has an opportunity to make a substantial contribution to one of society's pressing problems. Science classrooms provide the setting for helping students learn most, if not all, of the workforce skills described in Table 2. In order to

Table 3. Adapting 21st-Century Skills for Science Education Programs and Practices

Essential Features of 21st-Century Skills	Examples of Contexts for School Science Programs
Adaptability	
Cope with changing conditions Learn new techniques, procedures Adapt to different personalities and communication styles Adapt to different working environments	Work on different investigations and experiments Work on investigation or experiment Work cooperatively in groups Work on investigations in the laboratory and outdoors
Complex Communication Skills	
Process and interpret verbal/nonverbal information Select key pieces of complex ideas to communicate Build shared understanding Negotiate positive outcomes	Prepare oral and written reports communicating procedures, evidence, and explanations of investigations and experiments Use evidence gained in investigations as basis for scientific explanations Prepare a scientific argument Work with group members to prepare a report

Table 3. Adapting 21st-Century Skills for Science Education Programs and Practices (cont.)	
Nonroutine Problem Solving	
Uses expert thinking in problem solving Recognizes patterns Links information Integrates information Reflects on adequacy of solutions Maintains several possible solutions Proposes new strategies Generates innovative solutions	Recognizes the need to search for expert knowledge Recognizes patterns in data, evidence Connects evidence and information from an investigation with scientific knowledge from textbooks, the web, or other sources Understands constraints in proposed solutions Proposes several possible solutions and strategies to attain the solutions Proposes creative solutions
Self-Management/Self-Development	
Work remotely (individually) Work in virtual teams Self-motivated Self-monitoring Willingness and ability to acquire new information and skills	Work individually at home Work with a virtual group Completes a full/open investigation Reflects on adequacy of progress, solution, explanation Acquires new information and skills in the process of problem solving and working on investigation
Systems Thinking	
Understands an entire system Understands how changes in one part of system affects the system Adopts a "big picture" perspective Systems analysis Judgment and decision making Abstract reasoning about interactions among components of a system	Describes components of a system based on a system under investigation Predicts changes in an investigation Understands how small activity connects to big ideas Analyzes a system under investigation Makes decisions about best proposed solutions Demonstrates understanding about components and functions of a proposed system

accomplish this, science educators must provide opportunities for students to adapt to others' work styles and ideas, solve problems, manage their work, think in terms of systems, and communicate their results.

Learning outcomes aligned with inquiry and 21st-century skills can be attained using both full and partial inquiries. Central to these skills is group work and cognitive abilities such as reasoning. Although some may argue for full inquiries, and I agree that these should be part of a student's science experience, there is a place for partial inquiries. After all, the emphasis is on the learning outcomes, and these may be achieved with partial inquiry experiences. The important point is to give emphasis to the skills and abilities described earlier.

One challenge for curriculum, instruction, and assessment is implementing what I have called *integrated instructional sequences*. A National Research Council report, *America's Lab Report: Investigations in High School Science* (Singer, Hilton, and Schweingruber 2006) introduced the idea, saying, "Integrated instructional units connect laboratory experiences with other types of science learning activities, including lectures, reading, and discussion" (p. 4). I would argue that the BSCS 5E instructional model is an example of an integrated instructional unit. In a paper prepared for a National Research Council workshop exploring the intersection of science education and the development of 21st-century skills, I described the research supporting the 5E model and its links with 21st-century skills (Bybee 2009).

Using the BSCS 5E instructional model or another variation on the learning cycle provides connections among curriculum, instruction, and assessment and enhances students' opportunities to attain learning outcomes, including 21st-century skills.

Implications for Science Education Leaders

One of the consistent themes of educational leadership is that leaders have vision. Leaders with vision may, for example, have a long-term perspective, see large systemic issues, present future scenarios, or discern fundamental problems and present possible solutions, rather than spend time and energy assigning blame for the problems. Depending on their situations, leaders have diverse ways of clarifying a vision. Some may do so in speeches, others in articles, and still others in policies. One leader's vision may

unify a group, organization, or community; another's vision may set priorities or resolve conflicts among constituencies. A leader's vision likely will have many sources and result from extensive review and careful thought. This is especially true in today's complex educational system.

It also is the case that a vision generally implies change. Seldom does one hear a leader announce that his or her vision is the status quo. Rather, visions clarify the need for and direction of change and the implications for improvement. Some educational changes in science education come from within the system. For example, state assessments have implications for adoption of curriculum materials and learning outcomes. From time to time, changes in society influence changes in science education. For example, a small satellite launched by the Soviet Union resulted in a space race and major reform of science education. The changes implied by the need for 21st-century workforce skills also have originated outside of the science education community.

Effective leadership includes a plan to complement the vision. I have heard from individuals with a great vision, but no plan. Not much happens without a plan. Conversely, I have seen individuals in leadership positions with limited visions and thorough plans. The result in these cases often was great management and maintenance of the status quo. So, the complement to a vision of developing 21st-century skills is a plan to implement the changes implied by the vision. Here are some concrete recommendations that science education leaders can use as they implement changes that will enhance 21st-century skills as learning outcomes.

- *Make sure all students meet the standards for scientific inquiry and technological design.* Beginning with the national standards and extending to state and local standards, abilities related to scientific inquiry are included as learning outcomes. Statements of the need to develop the abilities of scientific inquiry and technological design can be the connection between what many will perceive as the abstract vision of 21st-century skills and the concrete context of science teaching.

- *Build on the opportunities that already exist in school programs and teaching practices.* Understandably, many will see the call for development of 21st-century skills as a major change, one beyond their capabilities and interests. Centering the changes on opportunities that already exist in investigations, laboratories, and activities will soften the resistance

to change. In many cases, science teachers already contribute to the development of these skills; the change is one of clarity and emphasis. In particular, some of the changes that may be new for science teachers include placing an emphasis on individual and interpersonal skills.

- *Emphasize cognitive abilities and skills as learning outcomes.* Bringing the development of cognitive abilities and interpersonal skills to the foreground in the science classroom may be new to science teachers. Providing teachers with statements they can use such as "What is the evidence for that explanation?" "What alternative explanations have you heard from your team?" and "What goals of the investigation include working together to gather evidence and form an explanation?" will help.

- *Use the idea of integrated instructional sequences.* Helping science teachers connect lessons will provide the time and opportunity needed for the emphasis on 21st-century skills. In addition, it will enhance the opportunities for other learning outcomes. Of course, I recommend using the BSCS 5E instructional model. But, the important idea is to use an integrated instructional sequence, not one particular model.

- *Include basic skills of literacy and mathematics as part of learning outcomes.* Because part of the student's work will include presentation of results, graphs, charts, diagrams and reports, the inclusion of basic literacy and mathematics should be considered part of a new emphasis on 21st-century skills.

As the leader moves from a vision and a plan to initiatives and actions within the educational system, paradoxes will appear. What do I mean by paradoxes? A paradox is a statement or situation that on the surface seems contradictory. Earlier I mentioned an often-heard paradox in education—equity for all students versus excellence for a few students. A paradox differs from a dilemma. A dilemma involves the selection of one alternative from two balanced alternatives. Dilemmas often defy satisfactory solutions; paradoxes may satisfactorily resolve themselves. For example, a leader must maintain continuity with past science programs and institute the changes implied by the inclusion of goals for skills for this century. Paradoxes may be perceived and expressed as tensions, contradictory directions, or con-

flicting issues. However, the elements seen as countervailing components of a paradox may not be as contradictory as they seem to be. Leaders in science education must master the paradoxes they confront. Let me describe several paradoxes faced by leaders.

One of the classic paradoxes of science education leadership is encouraging change in science programs and practices while supporting maintenance of past programs and practices. The resolution may center on maintaining stability in the major concepts of science while adopting a new inquiry-oriented science program and emphasizing additional learning outcomes of inquiry and 21st-century skills.

A second example of a paradox that leaders face involves being consistent and having a clear direction while being open and flexible. The resolution here may center on ultimate and proximate goals. The leader may have a consistent view of the ultimate goal he or she wants to attain; however, for now, the leader may have to accept changes that only partially represent the final goal. In between, the leader remains flexible and open to new ways of achieving the vision.

Along with the central importance of resolving the tensions of paradoxes, I would also add the importance of a leader's ability to recognize and address the political realities of educational work. The leader has to recognize that initiating changes means addressing the politics. All issues of improving science achievement are not solely educational. Indeed, it may be that *all* educational issues ultimately are political issues. The paradox embedded here can be stated as achieving educational goals while addressing political realities. I have found that "either/or" thinking often expresses the paradox, while "both/and" thinking provides insights into the resolutions.

Conclusion

Contemporary justification for a vision of improved science education resides in themes such as education and the economy, basic skills for the workforce, and thinking for a living. Such themes differ from earlier justifications such as the space race and a nation at risk. In many respects the economic rationale has emerged from the realization that the U.S. economy is part of a global economy and that the educational level of our citizenship influences the rate and direction of this country's economic progress.

Our discussion here, while this century is still young, presents the occasion to review the need for a workforce with 21st-century knowledge, abilities, and skills. What is common to the work of leaders? I proposed establishing a clear and consistent vision combined with a practical and workable plan. The vision and plan will get the leader moving in directions that may involve curriculum reform, instructional improvement, or alignment of assessments. One crucial point is that leaders must hone their ability to realize and resolve paradoxes as they execute their plans. Effective leadership requires initiating bold new practices while maintaining past traditions or fulfilling a national mandate such as developing new skills while incorporating a local agenda. One of the most disheartening paradoxes is the reality of achieving the established vision and enduring criticism rather than reward for attaining the goal.

Leadership in science education extends from science teachers to the Secretary of Education and the President of the United States. It does not reside with only a few people in key positions. Numerous systems and subsystems, each with individuals who have power, constituents, and goals, contribute to a better science education for students. Not every member of the science education community can or should be involved in constructing assessments, developing curriculum materials, presenting the arguments for scientific inquiry, defending the integrity of science, or providing professional development. But all of us do have our roles and responsibilities, and the extent to which we fulfill those responsibilities will ultimately make a difference for students as they live and work in the 21st century.

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Chapter 9

Technology Leadership for the 21st Century

Karen E. Irving

Literacy in the 21st century comprises more than simply reading and writing. In 2002, a study at the University of California, Berkeley School of Information Management and Systems, estimated that 5 exabytes (10^{18} bytes) of new information were stored that year on paper, film, and optical and magnetic media (Lyman and Varian 2003). This represents about 800 MB of new information per human and would require about 30 feet of books per person. To grasp the size of this new content, it helps to consider that 500,000 new libraries the size of the Library of Congress print collections would be needed to hold this information on paper. Between 1999 and 2002, new information, 92% of which is stored on hard disks and other electronic devices, grew about 30% per year. As of 2003, around the world, about 600 million people had access to the internet, about 30% of them in North America (Lyman and Varian 2003). To be an informed citizen in our contemporary information age, digital skills are needed by students, teachers, library/media specialists, administrators, and parents (Brooks-Young 2006).

Despite the perceived slow pace of educational technology integration in modern schools, information and communication technologies (ICT) are a driving force for change in education (Gurr 2004). In U.S. public school instructional spaces, 93% reported having had internet access in 2003 compared to 3% in 1994. In those public schools with internet access in 2003, 95% used a broadband connection. The student-to-computer ratio in 2003 was 4.4 to 1, a decrease from the 12.1 to 1 ratio reported in 1998 (Parsad and Jones 2005). As brick-and-mortar schools struggle to integrate and take advantage of their digital resources, virtual schools continue to evolve. In the 2007–2008 school year, virtual schools attracted more than a million students, which was a 47% increase from 2005–2006 (Davis 2009). Adapting and responding to the shifting educational landscape requires knowledgeable and capable leadership. This chapter addresses (a) how transformational leadership in the educational community is crucial for effective and appropriate infusion of educational technology as a fundamental part of K–12 education; (b) how educational leaders can create a robust digital age educational community that supports the use of advanced technologies in teaching and learning; and (c) how effective infrastructure may be provided for educational technology in K–12 schools.

Transformative Leadership

While hierarchical relationships are usually clear in the corporate world, views of educational leadership differ from traditional, leader-centered, top-down positional roles to include a variety of descriptions that account for how leadership adapts to site-based needs (Gurr 2004; Ladyshewsky et al. 2008). Transformative educational leaders adjust not only to situational conditions in schools, but also to the rapid and continuous changes in educational technology. Modern electronic technologies differ from earlier technologies like books, chalkboards, mimeograph machines, and film strips by the apparent anti-humanistic culture of the computer and its conflict with the person-centered work of school (e.g., Turkle 1984). Teachers are often poorly trained in the use of modern technologies, and they struggle to figure out how or why to integrate electronic technologies in their instructional practice. Most of the factors that researchers cite for the failure of teachers to use educational technologies (lack of training, lack of materials, unrealistic goals, insufficient hardware/software) can be

overcome. However, if school leaders do not believe in the importance and possibility of the innovation, then even the best conceived plans will lead to failure. Informed, transformational leadership that believes solutions are possible is critical to the success of educational technology integration in 21st-century schools (Kearsley and Lynch 1992).

From the variety of established theories on leadership, the cultural view best fits the ecology of technology in the school (e.g., Schein 1985). The cultural view of leadership is an evolutionary perspective in which the dynamic creation of culture and the shaping of that culture by its leaders are two sides of the same coin. A successful leader is able to view the culture that created the leader from an outside perspective, to identify the limitations of the culture in light of difficulties, and to initiate any needed adaptive changes. Building a school culture where educational technology innovation and integration are both accepted and expected requires engaging in shared values and beliefs. Participants at all levels, from teacher to state superintendent, must believe in what they are doing, be involved in the change process, and have a voice in the process. Otherwise, the well-documented obstacles of innovation diffusion will doom the initiative to failure (Rogers 2003). Different leadership skills and responsibilities fall to different levels of school administration, as illustrated in Table 1. Despite distinctions in responsibilities for individuals at different levels of governance, a commitment to a set of beliefs and values as well as emotional, political and financial support must occur at all levels.

While leadership is needed at many levels and may occur at the teacher level in individual schools, idiosyncratic integration patterns sometimes prove difficult to replicate across systems. A particular teacher or small group of teachers (for example, the mathematics department or science department) may take the initiative to explore and implement 21st-century technology in their classrooms. These efforts are often driven by genuine conviction about the efficacy of the innovation, and they build momentum as a result of individual teacher experiences. This type of spontaneous bottom-up leadership requires careful nurturance to develop beyond the limited interests of the smaller group into a systemwide community (Kearsley and Lynch 1992).

The complexity of school reform efforts coupled with the enlarging community of stakeholders has hastened the shift from traditional leadership roles in education. Rather than identifying the "right" educational

Table 1. Technology leadership skills (adapted from Kearsley and Lynch 1992)

Level	Skills
State	Identify a common format for computing across districts Statewide networks Funding for hardware/software Regional technology centers Professional development initiatives School-level evaluations Copyright policy
District	Funding sources for district-related purchases Districtwide administrative networks District-level objectives Inservice training schedules Attend to district-level needs
Schools	Funding sources for building-related purchases School-level networks and use priorities Access and opportunity for use within the building Technology training time and professional development Ethical use policies Highlight exemplary use
Teachers	Effective and appropriate classroom use Encourage student and parent involvement Interdisciplinary curriculum fit Improve personal efficiency Articulate and monitor ethical use policies
Technology specialists	Technology support to teachers/staff/administrators Develop new applications Fit applications to curriculum Information source for teachers/staff/administrators Articulate and monitor ethical use Recommend products for purchase Troubleshoot

technology, leaders work to promote change in their systems through people development and collaboration (Valdez 2004). Fullan identified five characteristics of effective leaders: "A strong sense of moral purpose, an understanding of the dynamics of change, an emotional intelligence as they build relationships, a commitment to developing and sharing new knowledge, and a capacity for coherence making" (2002, p.2). Transformative leaders create environments that nurture communities to implement creative and innovative integration of modern educational technologies.

Supporting Teachers and Students in the School Building

Specifically, how can educational leaders create a successful community for integration of educational technology in 21st-century classrooms? The ISTE National Educational Technology Standards (NETS) and Performance Indicators for Administrators address this issue and provide concrete suggestions (ISTE 2002, 2009). In addition to articulating and communicating their vision for technology use, leaders can create and implement a long-term, data-driven plan for achieving their vision. They can serve as local, state, and national advocates for research-based effective policies for technology integration that support relevant national and state standards and promote student learning and effective teaching. ISTE NETS recommend bringing stakeholders together to develop and plan implementation of their shared vision. Leaders can encourage and reward their communities, thereby sustaining an educational culture that both values and rewards instructional innovation that meets the needs of a diverse student body. By establishing, supporting, and modeling a robust and intentional use of educational technology in their own professional practice, individual teachers can establish a norm for others.

Transformative leadership allocates resources, including time and access to quality professional development related to the effective use of educational technology. Training for technology integration can occur through schools of education, state, and local agencies; through professional communities such as the National Science Teachers Association (NSTA) or the National Council of Teachers of Mathematics (NCTM); or directly through vendors. Webinars represent a recent addition to the professional development arena. A webinar (from *web* and *seminar*) is a type of live meeting or presentation conducted via an internet connection.

An important aspect of technology training is the career-long nature of the enterprise. Single-shot summer workshops or after-school technology training rarely provides sufficient knowledge to serve teachers in their technology integration efforts. Research on professional development indicates that successful programs begin with a commitment to a vision that includes identified and articulated educational standards, an analysis of student learning data, goal setting to address critical issues, group planning to select appropriate and effective strategies, implementation, evaluation, and reflection (Loucks-Horsley et al. 2003). Leaders can provide common planning time, release time, stipends, and funding to support sustained educational technology integration efforts (Zhao and Frank 2003). Recognizing the long-term nature of the commitment is a critical aspect of successful technology integration.

Learning communities of teachers, students, parents, administrators and staff that welcome innovation and 21st-century teaching methods need supportive collegial and administrative climates to flourish (Irving, Sanalan and Shirley 2009). Critical evaluation of technologies and careful fitting to meet schoolwide goals and curriculum requirements help teachers implement educational technology in pursuit of student learning. Timely information on educational trends and emerging technology can spark innovative strategies. The variety of classroom technologies that can be used to support and enhance learning encompasses a wide selection ranging from simple word processing programs to two-way audio and video links between learning spaces. The range and diversity can be overwhelming. Three broad distinctions about ways that the technology will be used can help to provide clarity and guidance: (1) students can learn *from* technology; (2) students can learn *with* technology; and (3) teachers and students can monitor classroom learning progress *through* use of technology.

Knowledge transmission provides the paradigm for learning *from* technology. Students receive knowledge from the information source; the technology serves as an electronic information delivery system (Reeves 1998). Examples include intelligent tutors, integrated learning systems (ILS), computer-assisted instruction (CAI), and computer-based instruction (CBI). These types of applications have found a place in classrooms for more than 20 years (Becker, Ravitz, and Wong 1999).

Construction of knowledge provides a useful paradigm for learning *with*

technology. Technology serves as a tool to engage students with real-world problem solving, conceptual development and critical thinking (Ringstaff and Kelley 2002). Students can engage in authentic inquiry, explore communication systems such as synchronous conferencing or interactive simulations, construct items such as robots or remote controlled devices, and express themselves with interactive video, animation software packages, or music composition software (Honey, Culp, and Spielvogel 2005).

Electronic audience response system (ARS) technologies have found a place in classrooms to help students and teachers track learning progress. ARS technology connects teachers and students with a networked system of handheld devices using software specifically designed for the classroom (Fies and Marshall 2006; Roschelle, Penuel, and Abrahamson 2004). Teachers and students receive timely and targeted information regarding learning progress when these devices are thoughtfully used during instruction. Studies with ARS technology have shown improved student achievement when coupled with constructivist-based pedagogical strategies (e.g., Owens et al. 2007; Hake 1998).

Supporting Teachers and Students Beyond the School Building

While educational technology integration efforts persist within the school building, virtual educational opportunities continue to grow at a record pace. Research consistently demonstrates that online schooling has the potential to be as good as or better in terms of student achievement than classes taught face-to-face in brick-and-mortar settings (e.g., Cavanaugh et al. 2004). A 2008 survey of U.S. School District Administrators conducted by the Sloan Consortium and Hunter College (CUNY) revealed that 75% of the respondents reported one or more students enrolled in a fully online or blended course (with both online and face-to-face components). The Sloan report estimated that during the 2007–2008 school year, about 1,030,000 K–12 students enrolled in online courses. The most commonly cited reasons for district administrators to offer online courses included (a) specialized needs for particular student groups; (b) broadening the course offering selections; (c) offering Advanced Placement or college level courses; (d) credit recovery (allowing students to retake a course they previously failed to "recover" credit); and (e) resolving scheduling conflicts

(Picciano and Seaman 2009). In 2006, Michigan was the first state to require students to complete an online course for high school graduation. Alabama has created a web-based professional development program for inservice teachers to promote increased content knowledge, improved teaching practice, and student achievement. In addition to students in traditional school settings, home-schooled students represent a potentially large and lucrative market for online learning. The online movement provides increased educational opportunities for students by removing or minimizing barriers that may exist in brick-and-mortar schools.

A variety of providers have entered the online learning field, including school districts, state-sponsored groups, charter schools, and for-profit vendors. The wide variety of *e*-learning courses introduces into the educational arena the element of competition for students. The potential for districts to lose per-pupil funding to online learning entities has attracted the attention of policy makers and budget directors. A critical issue is the difference between providers that *complement* existing schools versus providers that *compete* with them for student enrollment. Some cyber schools offer full-time enrollment opportunities and compete head-to-head with local school districts for students and funding over a broad geographic region. Other supplemental providers offer individual course opportunities that create new learning choices for students enrolled in traditional brick-and-mortar schools (Watson, Winograd, and Kalmon 2004).

Oversight of program quality for online learning represents an important challenge for school leaders. Many of the same characteristics of quality learning apply to *e*-learning and face-to-face instruction: course organization, curriculum design, instructional design, and student/teacher interactions. Technology and course delivery aspects are unique for *e*-learning environments and require special attention (McPherson and Nunest 2008). Statewide online offerings may benefit from quality oversight at the state level. Online courses offered by districts are subject to "local control" oversight similar to brick-and-mortar schools. Differences in program rigor may put some online courses at a competitive disadvantage with lower-quality courses offered by competing providers. One approach to providing oversight for quality, equity, and accountability is the establishment of and requirement for internal compliance mechanisms. Online programs formulate their own policies and goals, develop processes to meet these goals and submit reports to state, district, or other oversight groups. Internal

compliance mechanisms require education agencies to have sufficient staffing to provide meaningful oversight. Although virtual schools are expected to meet state content standards, mechanisms to check for alignment are often lacking. In some cases, state-generated end-of-course examinations serve as useful quality-control indicators for online courses (Watson, Winograd, and Kalmon 2004).

In addition to program quality, online learning raises the issue of teacher quality. While most states require online teachers to meet state licensure or certification standards, some (such as Michigan) recognize that the teacher may be licensed in another state. In this case, Michigan requires a certified teacher to be assigned to students as an on-site mentor. To protect student access to teachers, some states mandate that teachers of virtual courses be online and available for students on a daily basis during specified hours. Student-to-teacher ratios raise additional concerns in the virtual learning environment. Minnesota has set 40:1 as a limit for student-to-teacher ratios for online learning classes. California has mandated that the student-to-teacher ratio in the online world be substantially the same as in the "real classroom" (Watson, Winograd, and Kalmon 2004).

Student support for learning in an online world varies considerably. If the student attends a brick-and-mortar school and uses online courses as a supplemental learning opportunity, then student support can easily be provided through the school. A school online learning coordinator can help students with technical issues, check up on course progress, and monitor homework completion. For a cyber-school environment where a student enrolls in the entire educational program through an online learning vendor or state agency, no physical location may be available to provide students with this type of support. Parents, e-mail, or telephone calls may serve as a secondary support system (Watson, Winograd, and Kalmon 2004).

Providing a Reliable Technology Infrastructure

The task of providing reliable and compatible educational technology for schools requires leaders to consider both initial purchase plans as well as the often hidden costs of ownership. Compatibility with existing equipment, sufficient memory and adequate operating systems, manufacturer reliability, warranties, and performance record should be considered in

addition to price when making a purchase decision. Initial costs include not only hardware, software and peripherals, but also installation and professional development so that teachers are able to integrate the new technology into their instructional programs. Ongoing costs include routine maintenance, upgrades for hardware and possibly memory, repairing broken equipment, troubleshooting, technical support, and supplies such as batteries for handheld devices, printer cartridges, or projector bulbs (Brooks-Young 2006). One study estimated that ongoing costs may total one-third to one-half of the initial investment (Rothstein and McKnight 1996).

Technology-ready instructional spaces require careful planning. The work of teachers and students can be supported when consideration is given to both electrical and software requirements as well as the work patterns of the people who will actually work in the room. Sightlines, space for collaborative working groups, maintenance issues (can you easily pull out the computers to work on them?), access to USB ports for peripheral devices, and glare from classroom windows, if ignored, can render even the most expensive workspace inefficient for teaching and learning. Conversation with teachers and students regarding design of classroom technology rooms can provide architects and planners with valuable knowledge to design useful and productive spaces. An Internet connection on a wall opposite from the classroom computer creates a practical problem. Tech-ready facilities include appropriate furniture, thoughtfully planned traffic patterns, lighting that allows students to read digital displays, HVAC, and having electrical and network drops in convenient and usable locations (Brooks-Young 2006).

Software and network concerns can create headaches for both administrators and teachers. Denying teachers administrator rights to add and delete software from individual computer stations seems prudent in light of incidences when individuals have crashed entire networks by installation of incompatible or virus-infected programs. However, if technical support personnel are stretched thin, teachers may experience unnecessarily long wait times before the tech guy attends to their request. Sometimes software standardization policies require teachers to stop using older programs they have been previously using successfully in their classroom instruction. Frustration and discouragement might lead the teacher to stop any further technology integration efforts. Balancing the competing goals

of providing safe and secure computing resources for teachers, students, and staff with the cost of maintaining a network requires collaboration and active involvement of all stakeholders (Brooks-Young 2006). A reliable infrastructure is a necessary condition for a 21st-century school.

Conclusion

In summary, citizens in the 21st century live in a digital age in which the advance of electronic technologies in all aspects of life continues at an astounding rate. Transformational leadership in the educational community is critical for effective and appropriate infusion of educational technology as a fundamental part of K–12 education. Leaders who value quality teaching and learning can harness the power of strong communities of school-based and community-based leaders to direct the future of educational technology as a force in education. In the 21st century, educational opportunities at brick-and-mortar schools as well as through virtual learning communities will broaden opportunities for students of all ages.

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