Critical Issue:
Technology: A Catalyst for Teaching and Learning in the Classroom

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ISSUE:

The interface between educational technology and science and mathematics instruction is integral and symbiotic. Few of the examples noted in the Glenn Commission report (National Commission on Mathematics and Science Teaching for the 21st Century, 2000) would be as advanced as they are without the use of technology:

> Literacy in these areas [mathematics and science] affects the ability to understand weather and stock reports, develop a personal financial plan, or understand a doctor's advice. Taking advantage of mathematical and scientific information does not generally require an expert's grasp of those disciplines. But it does require a distinctive approach to analyzing information. We all have to be able to make accurate observations, develop conjectures, and test hypotheses: In short, we have to be familiar with a scientific approach. (p. 14)

Educational technology, especially computers and computer-related peripherals, have grown tremendously and have permeated all areas of our lives. It is incomprehensible that anyone today would argue that banks, hospitals, or any industry should use less technology. Most young people cannot understand arguments that schools should limit technology use. For them, use of the Internet, for example, plays a major role in their relationships with their friends, their families, and their schools. Teens and their parents generally think use of the Internet enhances the social life and academic work of teenagers:

> The Internet is becoming an increasingly vital tool in our information society. More Americans are going online to conduct such day-to-day activities as education, business transactions, personal correspondence, research and information-gathering, and job searches. Each year, being digitally connected becomes ever more critical to economic and educational advancement and community participation. Now that a large number of Americans regularly use the Internet to conduct daily activities, people who lack access to these tools are at a growing disadvantage. Therefore, raising the level of digital inclusion by increasing the number of Americans using the technology tools of the digital age is a vitally important national goal. (U.S. Department of Commerce, Economics and Statistics Administration, & National Telecommunications and Information Administration. (2000, p. xv)

The very concept of the Internet would not be possible without technology. This is paralleled by the incredibly rapid growth of information that likely would not be possible without this technology. Research centers with no computers would arouse suspicion about the completeness, accuracy, and currency of their information because science and mathematics information grows daily and much of that new information can only be found through the use of technology. In fact, very few would argue with the statement that computers are essential to the work of professional scientists and mathematicians.

From the beginning of the computer age, educational researchers and practitioners have told us that for technology use to be successful in our schools it needed to be closely tied to school reform. Glennan and Melmed (1995) wrote: "Technology without reform is likely to have little value: widespread reform without technology is probably impossible" (pp. xix–xx.). The unavoidable conclusion is that successful improvement of technology, science, and mathematics education is of high importance to our future. In 2002, 100 high-tech executives met with President Bush to discuss the future of technology: They indicated that improving mathematics and science education ranked next to national security and broadband Internet access was one of the most important considerations for improving economic growth in their companies.

Given the vital role of technology in today's world, t his Critical Issue will examine the value of effective technology use in classrooms with specific references to mathematics and science instruction, programs, and curricula. It will attempt to answer the following three questions that are essential to making technology use more effective in instruction :

1. What prevents educational researchers from giving us definitive answers about technology in the classroom that would satisfy both critics and advocates?
2. What does the best quantitative and qualitative research tell us about educational technology's effectiveness and the conditions and factors necessary for maximum effectiveness?
3. Why is educational technology important to the teaching and learning of mathematics and science and what are the important considerations and resources that make technology use more

effective?

OVERVIEW:

Teaching is changing and, in many ways, becoming a more difficult job because of increasingly numerous contradictory expectations, including the following:

- We are living in an age of information overload with the expectation that students will learn high-level skills such as how to access, evaluate, analyze, and synthesize vast quantities of information. At the same time, teachers are evaluated by their ability to have students pass tests that often give no value to these abilities.
- Teachers are expected to teach students to solve complex problems that require knowledge necessary across many subject areas even as they are held accountable for the teaching and learning of isolated skills and information.
- Teachers are expected to meet the needs of all students and move them toward fulfillment of their individual potential even as they are pressured to prepare students for maximum performance on high-stakes assessment tests that are the primary measure of student and school success.

Technology can actually assist with some of these expectations and make teachers—and their students—more successful. However, as the world becomes more complex—virtually year-to-year instead of the generation-to-generation pace of most of the last century—educational needs continue to shift from teaching and learning isolated skills and information within each content area, to teaching skills that enable students to solve complex problems across many areas. Educators must prepare for a technology-rich future and keep up with change by adopting effective strategies that infuse lessons with appropriate technologies. This makes a uthentic assessment needs even more important: Assessments must keep pace with effective instructional technology use. All this while educators at every level, but teachers especially, actively pursue professional development that enables a lifelong exploration of ways to enhance the teaching and learning of science and mathematics and support science and mathematics education reform.

The National Center for Education Statistics reports that there are virtually no differences in Internet access between poor schools and wealthier schools any more, as Internet access has steadily been increasing in public schools over time (Fox, 2005). Technology being infused into the schools is ongoing, unstoppable, and necessary. Thus, school use and access to new and current technologies is on the rise and more and more states have established technology standards for students, teachers, and administrators (Fox, 2005). Teachers have begun to use the Internet more frequently as a valuable tool in their instruction:

> Seventy-seven percent of public schools had a majority of teachers who used the Internet for instruction during the 2003–04 school year, up from 54 percent in 1998-99 … with 73 percent of high-poverty schools and 71 percent of high-minority schools having a majority of their teachers using the Internet for instruction. (Fox, 2005, p. 42)

On the other hand, the apparent growth of technology use is not always welcomed by critics who argue that schools should use less technology. For example, Oppenhimer (2003) in his book titled *The Flickering Mind: The False Promise of Technology in the Classroom* concluded that placing computers in the classroom has been almost "entirely wasteful." Other critics have written and spoken extensively of their beliefs that schools should not use technology for a variety of reasons ranging from creating social isolation to preventing students from learning critical basic skills.

This apparent paradox of technology use inexorably spreading across society—homes, businesses large and small, libraries, government—as critics continue to challenge its use in schools is even more puzzling when students are asked how important they believe technology and especially the Internet is to their lives and their schoolwork. The Pew Internet and American Life project (Levin & Arafeh, 2002) found that t eenagers use the Internet extensively. About 17 million students, ages 12–17, use the Internet to finding information for school research; that number represents 94 percent of the youth in that age bracket. According to the study, students are very positive about the use of the Internet to do their schoolwork:

> [Students] complete their schoolwork more quickly; they are lesslikely to get stymied by material they don't understand; their papers and projects are more likely to draw upon up-to-date sources and state-of-the-art knowledge; and, they are better at juggling their school assignments and extracurricular activities when they use the Internet. (Levin & Arafeh, 2002, p. ii)

However, student perceptions about the in-school uses of technology may be less positive, depending on several factors. One factor revealed in this study is student perception of insufficient teacher knowledge. Another factor students revealed is their disappointment in the lack of quality access and presence of excessive filtering systems that prevent them from accessing significant sites, especially those related to medical topics. They noted that while there were exceptions of positive and engaging uses of the Internet assigned by their teachers, they stated that Internet-related assignments were often of poor quality:

Students say that the not-so-engaging uses are the more typical of their assignments. Students repeatedly told us that the quality of their Internet-based assignments was poor and uninspiring. They want to be assigned more—and more engaging—Internet activities that are relevant to their lives. Indeed, many students assert that this would significantly improve their attitude toward school and learning. (Levin & Arafeh, 2002, p. iv)

Out of school, students use the Internet and handheld devices as major tools to maintain and enhance their social life and to communicate with friends locally and even internationally.

Overall, managing the changes in teaching (which surround and permeate implementation of technology use in schools) means dealing with student, parent, and institutional high expectations in student learning of high-level skills and content specifics as well as success on high-stakes assessments that tend to ignore many of those otherwise valued skills.

What Prevents Educational Researchers from Giving Us Definitive Answers About Technology in the Classroom That Would Satisfy Both Critics and Advocates?

There are several reasons K–12 educational organizations continue to agonize about how much and in what ways technology use in schools is appropriate. Their concerns include the following:

- Some uses of technology may add value while some may become a distraction for students.
- Technology is only one variable among many others that also need to be addressed.
- Teacher competency in the use of technology is often problematic.
- Students and teachers have unclear, and often inconsistent, expectations of technology use.

In considering research on technology, Fulton (1998) in an essay titled "A Framework for Considering Technology Effectiveness" noted that the following caveats must be taken into account:

- The technology keeps changing; as hardware and software evolve, new educational opportunities appear.
- Educational technologies are used in classroom settings, which rarely provide optimal conditions for their use.
- Research findings and results are often inappropriately generalized across grade levels, students, subject matter, types of technologies, and applications.
- The teacher is a key variable in technology implementation and effectiveness.
- Technology's impact on teachers and their practice should be considered as important as student effects because students move on but teachers remain to influence many generations of students

> (p. 1).

Meanwhile, the usually high value-added effects of classroom technology use have received more critical review than other educational tools. But too often both the praise and criticism of such technology use fails to consider the large and varied range of contexts found in classrooms. As Fulton (1998) also noted:

> In other words, to ask if technology works is almost the equivalent of saying "Do textbooks work?" Yes, some textbooks "work," in some conditions, with some teachers, with some students, but these same textbooks may not "work" in another educational context. Clearly, the question of technology effectiveness requires us to be clear in what results we seek, how we measure success, and how we define effectiveness. (p. 1)

Painter (2001) noted similar concerns regarding results, measures of success, and an effectiveness definition when developing technology evaluation instruments and protocols. She wrote:

> "What observable behaviors will indicate that technology integration is successful in this setting?" This discussion is likely to surface complexities that appear to be uniquely problematic to the area of technology integration. These issues relate to the complexity of technology integration, the confounding of teacher quality and philosophy with integration, the difficulty of inferring important information about complex cognitive processes from direct observation, and the rate of technology development that challenges evaluators' abilities to keep pace. (p. 22)

Indeed, many researchers believe that using paper-and-pencil tests to assess student learning after students had been taught content through the use of technology is the wrong thing to do and the wrong focus of technology use. Russell and Haney (1997) studied the effects of test administration mode to see whether tests administered on computer versus paper-and-pencil have an effect on student performance on multiple-choice and written test questions. The study found that significantly higher cognitive-level responses are written on computers than those written by hand:

> The size of the effects was found to be 0.94 on the extended writing task and .99 and 1.25 for the NAEP language arts and science short answer items. Effect sizes of this magnitude are unusually large and of sufficient size to be of not just statistical, but also practical significance (Cohen, 1977; Wolf, 1986). (Russell & Haney, 1997)

Such findings suggest that the medium of instruction makes a difference in the accuracy and value of assessment in the classroom. Russell (2000) claims that technologies used during learning activities should also be used during testing. Further, he contends that student assessment methods should match the medium in which students typically work and that advocates for state and local assessment programs should ensure students have access to the same technology in the assessment process as they have in the learning process. Rose and Meyer (2002) believe that selecting appropriate testing accommodations for students on an individualized basis is a very complex endeavor involving the following factors that can confound assessment results:

- Individual student learning differences.
- Media characteristics of the testing technology.
- Type and amount of student supports.
- Poor alignment between curriculum and the test used to measure achievement.

In their study, Russell and Haney (1997) concluded that, "As more and more students in schools and colleges do their work with spreadsheets and word processors, the traditional paper-and- pencil modes of assessment may fail to measure what they have learned." The study suggests that more and more paper-based assessments of today are becoming a thing of the past. Media characteristics of the technology used to administer the test also can present factors confounding test results when students are more apt in one medium (i.e., paper-and-pencil tests) than another medium (i.e., computerized tests that require keyboarding skills). This is a concern that will continue to grow as more assessments become technology based. Companies that develop these tests increasingly design their tests to be taken on computers. However, Rubin (Fulton, Feldman, Wasser, Spitzer, Rubin, & McNamara et al., 1996) believes that a more important outcome than raising test scores is the potential of technology to create communities of learners that do the following:

- Open the classroom to more communication opportunities.
- Encourage more teacher-student and student-student discussion.
- Share the authority as more resources are brought into the classroom.
- Create opportunities for tasks that are complex and authentic and connected to projects which may be multidisciplinary and long term.
- Give students more opportunities for multiple ways of discovering, creating, and communicating information in various formats and voices. (p. xviii)

In their studies, Haertel and Means (2003) provided guidance on the evaluation of technology and thereby provided ways to determine the effectiveness of educational technology. They noted as follows:

- Multiple and complementary research strategies are needed to measure the impact of technology.
- Three promising general strategies for research design are contextualized evaluations, multilevel

longitudinal research, and random-assigned experiments.

- Clustered studies that link to prior research and other interrelated studies offer a means for influences that affect student outcomes in "a myriad of relevant contexts."

- Common measures of contextual variables need to be used so that uniform results can be aggregated.

- Methods must be matched to purpose and not insistence on one methodology for all studies.

- Because of multiple intervention and practices present in every classroom, research on naturally occurring practices that are primarily descriptive need to be valued if they have longitudinal, carefully delineating and measuring variables, and use analytic techniques that help understand uses and frequencies. (pp. 257–268)

What Do the Best Quantitative and Qualitative Research Tell Us About Educational Technology's Effectiveness and the Conditions and Factors Necessary for Maximum Effectiveness?

Most educational researchers, especially those who have examined large numbers of controlled studies (meta-analyses) that were neutral and independent, agree that if used appropriately, technology can improve education in the effect-size range between 0.30 and 0.40 (Kulik, 2002; Waxman, Connell, & Gray, 2002). In order to make effect size more meaningful for nonstatisticians, Kulik (2002), in a section on methodology, stated the following:

> An effect size specifies the number of standard deviation units separating outcome scores of an experimental and control group. Effect sizes are positive when the experimental group outperforms the control group and negative when the control group comes out on top. Slavin, an expert in educational evaluation, considers effect size above 0.25 large enough to be educationally significant. Cohen, a pioneer in the use of effect size in the social sciences, classifies effect sizes of around 0.2 as small, 0.5 as moderate in size and 0.8 as large. (p. 1)

To achieve statistically significant effect sizes, schools must make certain that the following occur:

- There is sufficiently available technology support and maintenance, as well as appropriate software.

- The uses of technology have linkages to important educational learning expectations.

- Most important of all—teachers have the necessary skills and knowledge to effectively model and teach exemplary uses of technology.

Based on the effect size of 0.30 to 0.40, Kulik's (2002) conclusions were as follows:

> Computer tutorials can produce very favorable results in natural and social science instruction. Effects of tutorials on test scores in most studies were large enough to be considered educationally meaningful and were also unusually large for field studies in education. Tutoring effects on student attitudes toward instruction and science were also large. Evaluation studies suggest that student attitudes go up dramatically when students receive some of their instruction from computer tutorials…. Evaluation results from simulations and MBLs [microcomputer-based laboratories], however, were weaker and less consistent than were the results from tutorial programs. Although simulation programs sometimes improved the effectiveness of science teaching, … results from MBLs were usually small, and they were negative as often as positive.

But, as cannot be overemphasized, one factor that increases maximum effectives of technology use is good teacher preparation and skills. To be effective when using technology, teachers need to be highly involved by interacting and providing feedback to students. Researchers indicate that appropriate technology use can be very beneficial to increase educational productivity (Byrom & Bingham, 2001; Clements & Sarama, 2003; Kulik, 2002; Mann, Shakeshaft, Becker, & Kottkamp, 1999; Valdez, McNabb, Foertsch, Anderson, Hawkes, & Raack, 1999; Waxman, Connell, & Gray, 2002;Wenglinsky, 1998). Research studies (Chang, Henriquez, Honey, Light, Moeller, & Ross, 1998; Mann et al., 1999) indicate that technology may be most effective in science when technology is used to access information, especially from the Internet, and that information is used to communicate findings to others by using graphs, illustrations, and animations as well as to simulate and solve real problems. This seems to be especially true when scientific probes and other technology tools are used to assist with laboratory experiments. Teachers' views can help explain what research studies confirm.

Kristin Sak, a fourth-grade teacher and first-year science teacher at Bertha Vos Elementary School in Traverse City, Michigan, attests to the fact that technology can eliminate a lot of barriers of understanding—both in the classroom and among teachers—and explains how she approaches technology in her classroom. [Video: 1:00]

Research clearly indicates that the single most important factor in the effective use of technology is the quality of the teacher knowledge of effective technology uses in instruction. Coppola (2004) noted that:

> The effect of technology on students' access to knowledge is determined by the pedagogical knowledge and skill of teachers. Technology enables teachers with well-developed working theories of student learning to extend the reach and power of those theories; in the absence of these powerful theories, technology enables mediocrity. (p. xii)

Coppola (2004) was even more direct in her conclusions, stating that without strong teacher knowledge of ways to use educational technology, a lot of precious instruction time can be wasted:

> Whether computers are used well depends on the pedagogical knowledge and skill of the teacher, their use in the classroom. While it is possible to use computer in the powerful ways, … it is also possible to use them in ways that waste time or [are] actually detrimental to learning. (p. 4)

When used appropriately, technology acts as a great catalyst for learning in the classroom, says Eric Dreier, science coordinator and school principal at Traverse City Area Public Schools in Michigan. He notes that technology may often offer better and more accurate tools for students to search for solutions than regular probes and manipulatives. [Video: 1:15]

Chickering and Ehrmann (1996) considered the research findings of good practice in innovative technology-enhanced and technology-delivered education. They determined that there were at least seven factors as follows that were critical in manifesting effective good practice of technology use:

1. Encouraged contacts between students and faculty, especially those students who were unwilling to speak out in face-to-face classroom settings.
2. Developed reciprocity and cooperation among students allowing for the benefits of peer learning.
3. Used active learning techniques that made students active learners.
4. Gave prompt feedback.
5. Emphasized time on task.
6. Communicated high expectations.
7. Respected diverse talents and ways of learning. (pp.144–145)

There can be little doubt that technology is very important for all students; moreover, it can be critical for students in various subgroups, such as limited-English proficiency and students with special needs (Padrón & Waxman, 1996; Lee, 2000; Edyburn, Higgins, & Boone, 2005). As a caveat, one needs to differentiate between two types of technology, educational and assistive, as follows:

- Assistive technologies support students with disabilities. They can be virtually any device that increases, maintains, or improves the functional capability of a student with a disability.

- Educational technologies are learning tools that can increase virtually all students' learning opportunities.

Although researchers' degree of agreement fluctuates, instructional technology is generally recognized as a powerful means to boost student achievement (Kulik, 2002; Waxman, Connell, & Gray, 2002). But for technology to work, curriculum and instructional methods need to be expanded to match the variety and rich learning options that these technologies are making possible. Educators also understand that technology itself has created tools that can assist. They realize that assistive technology is about using simple implements like a pen grip or overhead projector as well as sophisticated software and adaptive hardware, so each learner has an opportunity to achieve. They recognize that technology integration means using many technologies to enhance teaching, learning, and multisensory experiences, providing "a range of pathways for students at varying levels" (Ficklen & Muscara, 2001, p. 26). For more detailed information on technology uses with LEP students and students with special needs, see Using Technology to Support Limited English Proficient (LEP) Students' Learning Experiences and Enhancing System Change and Academic Success Through Assistive Technologies for K–12 Students with Special Needs.

Why is Educational Technology Important to the Teaching and Learning of Mathematics and Science and What are the Important Considerations and Resources That Make Technology Use More Effective?

Mathematics and science have suffered from the stereotype that only a few people can and in fact need to be highly proficient in science and mathematics. An equally unfortunate and false stereotype is that primarily white males have the capability to become scientists and mathematicians. Barton (2002) provides compelling statistics about why those perceptions need to be changed:

> While the number of 18- to 24-year-olds will grow by 3 million by 2010 and offer possibilities of a fresh supply of scientists and engineers from our colleges and graduate schools, there is one striking fact about that population increase: only 3 in 10 will be White. (Among all 18- to 24-year-olds, the percentage of those who are White will decline from 66 to 62 percent). White students currently represent [a] disproportionately large share of degree recipients. Blacks, Hispanics, and American Indians—who are currently underrepresented in college and graduate school programs—will constitute almost 60 percent of the population increase over the next decade. And as pointed out above, only 3 or 4 percent of high school seniors from these subgroups currently reach the "proficient" level in mathematics. While the growth in the proportion of these minorities in the 18- to 24-year-old population is not dramatic, it does point toward need for greater effort to improve their educational achievement. Together these facts make it clear that meeting our nation's future economic needs will not be possible without improving the math and science achievement of underrepresented minorities . (p. 4)

Meanwhile, the educational role of technology has grown tremendously in several ways proving that technology use is undeniably capable of, and important for, helping teach content. As noted in NCTM (Suydam, 1990, as cited in Jarrett, 1998):

> Today's technology can offer adolescents a bridge from concrete to abstract thinking, enabling them to observe and create multiple representations of mathematical ideas: numerically, graphically, and symbolically. For example, students can use geometric construction software to investigate the relationship between the circumference and diameter of a circle. They can measure several round objects and record the circumference and diameter (numerical representation). They can plot the values and estimate a "best

> fit" (graphical representation). Students can then determine the best fit equation (symbolic representation). Technology can also help teachers respond to students' diverse learning styles by creating rich environments that engage students' tactile, visual, and auditory senses. Finally, information technologies such as word processing, calculators, spreadsheet tools, and the Internet can enable middle-grade students to begin learning higher communication and problem solving skills—abilities that are essential to mathematical thinking. (pp. 4–5)

Educational technology is now widely valued for its ability to enhance one of the most significant intellectual developments for students: their emerging ability to think abstractly (Jarrett, 1998, p. 4).

Technology has become a very powerful instructional tool to develop abstract thinking, which should be reflected also in assessment, says Dr. Valdez. [Video 1:20]

One of the necessary characteristics of the effective use of technology is that it be used for authentic tasks. According to Means and Olson (1997, as cited in Jarrett, 1998), there are the following important considerations for fostering the authentic uses of technology:

- The technology supports student performance of complex tasks that are similar to those performed by adult professionals and/or fill a genuine need of the student.
- The technology is integrated into activities that are a core part of the classroom curriculum.
- Technology is treated as a tool to help accomplish complex tasks (rather than as a subject of study for its own sake) that engage students in extended and cooperative learning experiences that involve multiple disciplines. (p. 14)

Technology has been proved to accommodate learning styles and to be an effective motivator for students with specific learning needs. Furthermore, students working in collaborative-team-learning settings appear to function better when learning events are accompanied by technology use. In addition, technology also is important when used to provide distance-learning opportunities to students who otherwise would not have access to course offerings. Distance education is especially important to students in rural settings because many high school courses that are necessary prerequisites in universities, such as higher mathematics and science offerings, are less available because of the fewer numbers of students in smaller schools.

In contrast to the statement above supported by The National Center for Education Statistics (Fox, 2005) that there are virtually no differences in Internet access between poor schools and wealthier schools, equal access to technology—especially in families of high poverty—continues to be a problem. The National Center for Education Statistics (DeBell & Chapman, 2003) study reported that among the group of children and adolescents who access the Internet at only one location, 52 percent of those from families in poverty and 59 percent of those whose parents have not earned at least a high school credential do so at school. In comparison, 26 percent of those from families not in poverty and 39 percent of those with more highly educated parents do so only at school. This illustrates the role of schools in bridging the digital divide.

A reasonable conclusion is that classroom computers and other technology can play many instructional roles, from personal tutor and information source to data organizer and communication tool. So, it is important for teachers to consider how computers and other electronic technologies can enhance the learning experiences of students and increase their productivity. The primary conclusion of much of the research is that t echnology has considerable potential for increasing interest in, and improving the quality of, learning in science and mathematics classrooms. However, effective use of instructional technology is possible only if sufficient attention is given to the following:

- Curriculum uses.
- Instructional pedagogy used.
- Assessments used.
- Sufficiency of technology and access to the Internet.
- Ability of the teacher, especially, to model uses of technology.

GOALS

- Educators and key stakeholders will develop a technology vision (See Why develop a technology vision?) to support learning goals that are focused on improved student learning and teacher effectiveness. (See How will you use technology to support your vision of learning?)
- Educational leaders and teachers will design and implement the necessary professional development plans to ensure that teachers have the knowledge and skills to successfully implement technology in mathematics and science. (See NCREL's planning resource for technology professional developers: Supporting Technology in Education With Professional Development.)
- Teachers and students will be able to use computers and other electronic technologies in ways that increase student learning, motivation, personal productivity, and creativity.
- Educational leaders and stakeholders will develop sufficient knowledge of change process research to anticipate and address change problems and issues in schools.

 **ACTION OPTIONS:**

Any effort to create and encourage the effective use of education technology in instruction and assessments must consider specific issues of consistency, continuity, and support. Some of them, sorted by area of stakeholders' responsibility, are as follows.

School Board Members

- School board members and their relevant policies should be explicit about the value of technology use in every appropriate venue. However, support for technology use must be expressed through actions, investment, and access, wherever feasible, not just with words.

- School board members can promote student and teacher excellence through technology use by not creating isolated technology improvement efforts that have no connection to real-world uses and promote learning.

- School board members should continually inform and communicate to the community why use of technology in schools is essential if students are to be prepared for future work and to fully participate in a technology-based information society.

- School board members need to secure the necessary technology resources and ensure that technology integration is treated as an ongoing endeavor and not isolated from systemwide improvement efforts.

- School board members should actively demand and support the creation of accountability systems that track the use and impact of technology use.

- School board members must learn not to treat technology as a one-time cost. Ongoing maintenance, support, and replacement of software and hardware are large costs that must be added to the budget as line items and should be evaluated by where and how they add value (not cost) to the school district. This practice should be institutionalized so that new board members cannot easily slow such investment and support.

- School board members must support investment in the necessary human infrastructure—such as effective technology-use professional development, active assessment alignment, and grade-level continuity—to ensure effective technology use and hardware infrastructure.

- School board members need to stay up to date about the functional capabilities needed to engage students in 21st century learning experiences that are necessary to have their school district provide relevant education appropriate for their students' future.

- School board members must make every effort to stay informed about technology research on its best use and impacts on learning.

Administrators

Leaders who are trying to make technology more effective in improving learning are fortunate that a great deal of thought has been given to defining standards. James Bosco, chairperson of the Technology Standards for School Administrators (TSSA) Committee, noted in the introduction to *Technology Standards for School Administrators:*

These Standards enable us to move from just acknowledging the importance of administrators to defining the specifics of what administrators need to know and be able to do in order to discharge their responsibility as leaders in the effective use of technology in our schools. (Technology Standards for School Administrators Collaborative, 2001, p. 1)

The TSSA document, a product of the TSSA Collaborative, is a useful guide that articulates the following main technology standards for administrators:

- Leadership and Vision: Educational leaders inspire a shared vision for comprehensive integration of technology and foster an environment and culture conducive to the realization of that vision. (p. 6)

- Learning and Teaching: Educational leaders ensure that curricular design, instructional strategies, and learning environments integrate appropriate technologies to maximize learning and teaching. (p. 6)

- Productivity and Professional Practice: Educational leaders apply technology to enhance their professional practice and to increase their own productivity and that of others. (p. 6)

- Support, Management and Operations: Educational leaders ensure the integration of technology to support productive systems for learning and administration. (p. 7)

- Assessment and Evaluation: Educational leaders use technology to plan and implement comprehensive systems of effective assessment and evaluation. Analysis of data is especially important because of the requirements found in the NCLB Act. (p. 7)

- Social, Legal, and Ethical Issues: Educational leaders understand the social, legal, and ethical issues related to technology and model responsible decision-making related to these issues. (p. 7)

- In addition, school administrators need to make certain that all segments of the community have representation on planning committees, giving special attention to the inclusion of traditionally underrepresented members of the community.

Readers are encouraged to view NCREL's *Pathways* Critical Issue titled Technology Leadership: Enhancing Positive Educational Change. The article deals with leadership strategies for use of technology to improve learning successfully.

Teachers

Representatives of appropriate organizations also have created technology standards for teachers. The following are teacher standards modified from the National Educational Technology Standards for Teachers. They are especially relevant for teachers considering the following technology action options:

- Teachers understand and support the importance of students learning to use educational technology as an important component of their preparation for further education, work, and life in general.

- Teachers demonstrate their support of technology use by developing their own skills, knowledge, and strategies necessary to model effective uses of technology.

- Teachers learn and use effective ways to integrate technology into their curriculum and use technology in ways that enhance instructional opportunities and successes for all students.

- Teachers learn uses of technology that provide assessment feedback to parents, students, and the teacher about how well the student is learning, and then use that data to improve learning productivity.

- Teachers understand and instill into their students the social ethical, legal and human issues surrounding the uses of technology

Students

Student standards have been developed by the International Society for Technology (ISTE), which recommends students' use of technology should reflect the following skills and operations:

- Basic operations and concepts

    - Students demonstrate a sound understanding of the nature and operation of technology systems.

    - Students are proficient in the use of technology.
- Social, ethical, and human issues
    - Students understand the ethical, cultural, and societal issues related to technology.
    - Students practice responsible use of technology systems, information, and software.
    - Students develop positive attitudes toward technology uses that support lifelong learning, collaboration, personal pursuits, and productivity.
- Technology productivity tools
    - Students use technology tools to enhance learning, increase productivity, and promote creativity.
    - Students use productivity tools to collaborate in constructing technology-enhanced models, prepare publications, and produce other creative works.
- Technology communications tools
    - Students use telecommunications to collaborate, publish, and interact with peers, experts, and other audiences.
    - Students use a variety of media and formats to communicate information and ideas effectively to multiple audiences.
- Technology research tools
    - Students use technology to locate, evaluate, and collect information from a variety of sources.
    - Students use technology tools to process data and report results.
    - Students evaluate and select new information resources and technological innovations based on the appropriateness for specific tasks.
- Technology problem-solving and decision-making tools
    - Students use technology resources for solving problems and making informed decisions.

- Students employ technology in the development of strategies for solving problems in the real world.

Parents

The following are recommendations of what skills, knowledge, and dispositions parents are expected to develop in terms of technology use :

- Parents should understand the importance, benefits, and issues associated with informational uses of technology in schools.
- Parents share with their children the importance and concerns they have about the uses of technology.
- Parents are involved in school activities, including helping students become more successful users of technology.
- Parents advocate for better educational opportunities for their children, including better access and use of technology.
- Parents model and provide guidance to quality uses of technology outside of school, including adhering to copyright laws and understanding the benefits and challenges of the vast and diverse materials available on the Internet.

IMPLEMENTATION PITFALLS:

Some researchers believe that there are so many barriers to successful implementation of effective technology use in U.S. schools, and they are so prevalent, that it is very difficult to isolate and measure just how much effective technology use is actually in place in the schools. Some generic reasons for the failure of educational change-and-reform efforts are important to note, reasons which may certainly apply to efforts to create effective technology use. Fullan and Stiegelbauer (1991) indicate the following reasons:

- The purpose is not made clear.
- The participants are not involved in the planning process.
- The appeal is based on personal reasons.
- The habit patterns of the work group are ignored.

- Communication regarding change is poor.
- There is fear of failure.
- Excessive work pressure is involved.
- The cost is too high, or the reward for making the change is seen as inadequate.
- The present situation seems satisfactory.
- There is a lack of respect and trust in the change initiator.

Likewise, there are many factors that affect technology implementation, especially in urban schools (Means, Penuel, & Padilla, 2001, p. 197), including the following:

- Lack of technology infrastructure.
- Lack of technical support.
- Teacher discomfort with technology.
- Lack of high-quality digital content.
- Lack of instructional vision for technology use.
- The constraints of academic schedules and departmental structures.
- Lack of student technology skills.
- Low expectation of students.
- Accountability pressures.

Gabriela Castillo, a first-grade bilingual teacher at Johnson Elementary School in Community Unit School District 200 in Wheaton, Illinois, stated issues such as lack of access to a computer laboratory, limited software functions, and insufficient interaction among classroom teachers and computer teachers often act as barriers to successful use of technology with students. [Video 2:00]

Managing Technology-Use Initiatives

Many of the barriers to implementation, as Means, Penuel, and Padilla (2001) noted, are self-explanatory, while some require clarification. Take, for example, the different uses of technology by departments in secondary schools. In those locations where principals and department heads are able to provide concrete, specific examples of how technology can support learning, there can be more quality use than in those locations where such guidance is not provided (Means, Penuel, & Padilla, 2001). Block scheduling with its longer time periods also encouraged in-depth projects where technology could be used with the most effectiveness. One of the most challenging barriers is that of low expectations for student decision making. These lower expectations result in teachers assigning primarily drill-and-practice uses of technology rather than the student-centered and complex tasks that offer the greatest value-added opportunities for the use of technology (Means, Penuel, & Padilla, 2001, pp. 197–208).

Meanwhile, affecting all of this planning and effort is, of course, all the communication and leadership pitfalls to implementation that are factors in other change efforts are also true when stakeholders attempt to provide educational technology-use leadership. Failure to have a shared vision, clear goals, and objectives with defined measurable outcomes can kill a change effort right from the beginning. A poorly designed implementation plan that fails to define tasks, responsibilities, and ongoing benchmarks also will result in the change effort failing. Clearly, failure to assess progress and challenges and to make needed changes as the program progresses is an implementation pitfall with dire consequences. Also, administrators who do not communicate with stakeholders about defining success and challenges increase the risk of failure dramatically.

A careful plan may avoid several pitfalls. But those careful plans may be surprised, short-circuited, or defeated by people, institutions, rules, policies, or inertia: These are barriers to implementation of such scale that they cannot be treated as mere pitfalls. If barriers to implementation are not dealt with, the chances of success for even the best-planned implementation is seriously compromised.

These are all extremely important implementation pitfalls to avoid and barriers to overcome, but there are some problems unique to technology leadership that require special attention. One of the most significant is the need for professional development for both administrators and teachers. Because many educators did not receive adequate preparation for use of technology in their preservice experience, most have to learn effective and efficient use even as they try to instruct and model use of the available technology.

Such insights suggest that instructional technology use, if it is to be successful, needs to be implemented systemically rather than in isolation. For example, failure to integrate technology use into the required curriculum may result in technology being perceived as an instructional add-on. Teachers may be frustrated when they realize that to use technology effectively, they will need not only to learn technology use and integration but that they may need to modify their instructional and assessment practices as well. Meanwhile, administrators need to share the change process, beginning with why the change is necessary, what the benefits expected are likely to be, and what the consequences are of not making any changes, with respect to the emphasis on providing a full education to all students. In addition, administrators need to encourage and support technology professional development opportunities exactly because some teachers are less comfortable with technology than with other aspects of their teaching. However, some teachers may need additional constructive feedback that will enable them to take risks using technology in ever more ways.

Creation and management of technology infrastructure and support is probably the implementation problem that can be most fatal. Teachers and students should not be expected to be technology infrastructure and support experts. The equipment they are using needs to be dependable and easily accessible. Teachers need to experience technology as something that they can build lesson plans around and not worry that their planning efforts and schedules are frequently impossible because of equipment failure or unavailability. A few negative experiences will lead teachers to believe that technology use is more problematic than helpful and will likely reduce their technology use substantially.

DIFFERENT POINTS OF VIEW:

Routinely, articles and books are published that continue to make the argument that schools use too much technology. Some critics attack technology use in schools for physiological, psychological, moral, and physical reasons, and those critics and their opinions may never change. However, most critics attack technology use because they believe it provides minimal value-added benefit to educational efforts. *Fool's gold: A critical look at computers in childhood* (Cordes & Miller, 2000), *Oversold and underused: Computers in the classroom* (Cuban, 2001), and *The Flickering Mind* (Oppenheimer, 2003) are three critiques that have received considerable attention as serious criticisms of technology use in schools.

The main criticism in all three of these books, and other critical articles as well, is that computers are not as cost effective as other interventions. They note the obsolescence factor of computers and the ongoing costs of upgrading both hardware and software. Some critics indicate a belief that many hardware and software companies purposely design products to become quickly obsolete and thus require updates that educators must buy. It is their belief that educational technology is too much in its infancy and not yet reliable enough for use by most students.

Some critics such as Kirkpatrick and Cuban (1998) indicate that technology equipment requires extensive support structures that require districts to take money away from basic expenditures for other and better uses in the classroom. They believe this money should be invested in the arts, science laboratories, shops, and anything else that involves more hands-on ways of learning. Technology literacy, some believe, is highly overblown in its importance and that people who need to use technology will learn by using task applications that involve "real" work.

The criticism is especially strong for computer use by younger students. Some critics believe that with the exceptions of assistive technologies for students with special needs, students below the third grade should not use much, if any, technology. Other critics are concerned that technology reduces socialization opportunities. Some parents are concerned about the effect that children are gaining so much of their world knowledge from a virtual, rather than the real, world. Other critics are concerned that the sexual and violent content accessible on the Internet challenges or prevents character education necessary for development of moral citizens (Rifkin, 2000).

Some critics think that technology use is a wasteful and negative use of scarce resources and give examples of visiting schools where uses of computers are actually making education worse. They note that in many cases, teachers use computers to entertain students with irrelevant and unconnected activities because it makes their teaching lives easier and not because it benefits students as they learn important content.

Subsequently, several people have written very enlightening responses to such critics. Two articles that are especially informative are "Myths and Realities about Technology in K–12" by G. M. Kleiman (2000) and " Strip Mining for Gold: Research and Policy in Educational Technology—A Response to *Fool's Gold*" by D. H. Clements and J. Samara (2003). Kleiman (2000) indicated that there are realities to some of the criticisms but that many of the points of objection are due to poor implementation of technology. He noted:

The central theme underlying all these myths is that while modern technology has great potential to enhance teaching and learning, turning that potential into reality on a large scale is a complex, multifaceted task. The key determinant of our success will not be the number of computers purchased or cables installed, but rather how we define educational visions, prepare and support teachers, design curriculum, address issues of equity, and respond to the rapidly changing world. As is always the case in efforts to improve K–12 education, simple, short-term solutions turn out to be illusions; long-term, carefully planned commitments are required. (p. 20)

No doubt, technology will always have critics. Some believe that technology reduces hands-on experience and student engagement in active participation. Others believe technology reduces important human contact. In the final analysis, one can conclude that identified uses of technology can have different critiques depending on one's personal values and perspectives of what is good and bad in education. The single most important factor for reducing criticism of technology use in instruction is to have teachers who are competent and knowledgeable about appropriate and effective use of technology to improve student learning.

ILLUSTRATIVE CASES:

Following are a few exceptional resources focused on effective uses of technology in schools:

- **Global Learning and Observations to Benefit the Environment (GLOBE).** Through involvement in the GLOBE program, students join other students around the world to measure water temperature at a nearby stream or to track changes in the weather from day to day.
- **One Sky, Many Voices.** This program, based out of the University of Michigan , provides

students with interactive activities across many communities and provides them with opportunities to use technologies in interesting and exciting ways.

- **Pathfinder Science.** The motto of this Web site is creating student scientists, not just science students. Pathfinder Science is a virtual community that provides projects, background information and a structure for students to follow in gathering, analyzing, and sharing data using the Internet.

Additional Links

Central Operations of Resources for Educators (CORE)

This Web sitedescribes more than 200 aeronautics and space programs chronicling NASA's state-of-the-art research and technology efforts. These videocassette, slide, and CD-ROM programs can serve as a springboard for discussing life science, physical science, space science, energy, Earth science, mathematics, technology, and career education.

The Earth Exploration Toolbook

This Web site has a collection of computer-based Earth science activities. Each activity, or chapter, introduces one or more data sets and an analysis tool that enables users to explore some aspect of the Earth system.

Eisenhower Mathematics and Science National Clearinghouse Digital Dozen

This Web site offers 12 new exemplary curriculum features and resources each month. It identifies effective curriculum resources, creates high-quality professional development materials, and disseminates useful information and products to improve K–12 mathematics and science teaching and learning.

Exploratorium

This Web site offers numerous resources such as The Tools for Teaching, an important stop for all science teachers.

Federal Resources for Educational Excellence

More than 30 federal agencies formed a working group in 1997 to make hundreds of federally supported teaching and learning resources easier to find. All can be accessed from this site.

Geometry Java Applet Gallery

This Web site provides applets to triangle calculators and advanced principles in an interactive manner and demonstrates excellent uses of technology to improve learning.

Illuminations

The Illuminations Project is designed to illuminate the vision for school mathematics described in NCTM's *Principles and Standards for School Mathematics*. Illuminations is a partner in the Marcopolo Internet Content for the Classroom program.

Intel Innovation in Education

This Web site features project-based activities that model interesting and relevant learning and effective uses of technology.

ISTE National Educational Technology Standards (NETS)

In partnership with a number of organizations and educators across the country, ISTE has developed National Educational Technology Standards (NETS) for students.

Knowledge Network Explorer

This Web site offers many resources, including Blue Web'n that classifies Internet resources rated on a five-star scale.

Manipula Math With JAVA

This Web site features interactive programs that teachers and students can manipulate as well as animation that helps students grasp the meaning of mathematical ideas.

Materials Across the Curriculum Electronic Bookshelf

This Web site offers numerous resources for teaching mathematics in an interdisciplinary manner.

NASA SCIence Files

This Web site is a must for teachers: The activities found here demonstrate how exciting the interface of technology and learning can be when done well.

NCREL's Educational Technology Resources

Some resources here focus on technology and its use in education, while others focus on related issues such as professional development and policy, which have an educational technology component.

Ohio Resource Center

The mission of the Ohio Resource Center is to identify and disseminate effective online instructional and professional development resources to schools, school districts, and higher education in Ohio.

Online Educational Resources for Physics Teachers

This is a large collection of Java and other interactive tools and resources of value to science and mathematics teachers, especially those teaching physics.

Science NetLinks

This Web site provides numerous Internet experiences and resources for K–12 science educators and students that address important science standards. The tools and resources sections are especially valuable.

United States Geological Survey

This Web site provides an unbiased, timely, relevant, and impartial study of the landscape, natural resources, and natural hazards.

Your Sky

This Web site allows users to enter their precise geographic coordinates (or choose a city from a list) to get sky maps in three different views. The site has information valuable to the beginner as well as the most advanced sky watcher.

Weather Scope: An Investigative Study of Weather

This is an essential Web site for the study of weather.

Why Files: The Science Behind the News

Based at the University of Wisconsin-Madison, this Web site presents information related to science, mathematics, and technology based on daily news items to make a clear connection between science and daily life.

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- Educational leaders and stakeholders will develop ongoing formative assessments and summative evaluations of program plans that can effectively guide the successful implementation of tasks and inform them when they have accomplished the desired instructional-technology goals.

Return to "Technology: A Catalyst for Teaching and Learning in the Classroom."

Kristin Sak: Lesson Study

Kristin Sak

Fourth Grade Teacher
Bertha Vos Elementary School
Traverse City Area Public Schools

VIDEO TRANSCRIPT:

I used the LCD projector to show some of the chemical reactions that were happening within our experiment, and one of them is the heat test. And we don't have the children do that because they have to, you know, light a candle, …hold it over and just pour that—a whole reason for if somebody burns themselves… It wasn't appropriate. And I was able to show that under the LCD projector, of the actual current happening, everybody could see it at the same time. Afterward, we used a small part. I have a microscope that I plug into my laptop, which I hook up to the AVerKey, and then they can look at my, the microscope and what I put underneath it and the whole class can see it and they can take clips, and then I can save it to a PowerPoint, so, a lot of those kind of things. We can examine student work, e-mail—I guess it's been around so much I forgot that it's technology. But I can e-mail other fourth-grade teachers in the district and share information. Kids can use Internet to get information, to look up things.

Eric Dreier:
Technology as a Learning Catalyst

Eric Dreier

Science Coordinator
Traverse City Area Public Schools
Michigan

VIDEO TRANSCRIPT:

We have adapted [technology use in] the district in many levels, not just the advance sciences, as we've asked kids to use greater amounts of technology. Sometimes those are computer-based problems; of course, in many cases it's the use of probes and other measurement tools. But to use one very specific example—in our Lesson Study project, when we were doing some things with mass and density, we were realizing kids weren't quite getting this right. Well, they had poor tools and by enhancing the technology in the classroom, we were able to give them some specific scales that gave them very accurate measures very quickly. And they were able to progress and come up with far better solutions and, therefore, [better] data and conclusions than they had before. So we were very, very pleased with that. So technology as a whole has acted as a very good catalyst, and it's been able to pull together resources that we had formerly used with teaching skills. And there's no question, in our mind, the evidence is there to say students are learning more.

Gilbert Valdez:
Value of Technlogy in Aiding Abstract Thinking

Gilbert Valdez, Ph.D.

Director
North Central Regional Technology in Education Consortium
and Codirector of the North Central Eisenhower Mathematics and Science Consortium (NCEMSC)

VIDEO TRANSCRIPT:

The value of technology is to add productivity to learning. If you think about what the tractor did for farming, this is what technology can do for learning and it's become a necessary productivity tool for the future. If you look at 21st century skills, they're going to be requiring the use of technology very effectively. And some of the things that we most should be testing are those abilities to find, evaluate, and package in a different way—more meaningful according to the audience—that knowledge, and not necessarily looking for what did somebody say before was the—because there may be no right answer. Or more often nobody has ever answered that particular question because the knowledge is new. So, I think what technology does is serve as a very powerful tool which means that in assessment, if you're going to assess for it, you better have that tool as a part of the assessment instrument, or assessment strategy. It's kind of ridiculous to think that we could assess very powerful uses of technology with paper-pencil or multiple-choice questions, when in fact, you really have to talk about: can the student do the task …that you're trying to document.

Gabriela Castillo: Barriers to Successful Use of Technology

Gabriela Castillo

First Grade Bilingual Teacher
Johnson Elementary School
Wheaton, Illinois

VIDEO TRANSCRIPT:

This is probably one of the hardest questions. Because at first grade we have—okay, in my classroom we have two computers right now and it would be ideal to say, okay, I have a computer for, you know, for every student, for every group of students so – but it's not going to happen. But I think that scheduling in the computer lab and being in such a large school, and trying to get into the computer lab, you know, when you need it, and in a standards-based classroom sometimes …you know, you're doing something and we end up doing – not doing something else completely, but because of what the kids want to learn, because of their questions—sometimes we end up doing something else. And it would really be nice to say okay, you know, let's go up to the computer lab so I can show you what I'm talking about. But because of the scheduling in our computer, in our lab here at our school… it's not possible. And because we only have the two computers here in the classroom, you know, I could only have maybe four kids on a computer at a time. And also the collaboration with the computer teacher, we—there needs to be more collaboration, I think, between the classroom teacher and the computer teacher to show us how to use some of that new technology. And I think that a lot of the software that our school has, and I think this probably is—I'm veering off a little bit. But the software that we have is—it gives the students the opportunity to practice those computation skills, it—but it doesn't really—there—the software isn't like open-ended, you know. So it doesn't give the kids a lot of the opportunity to create problems or to—I guess just to—you know, just to be more creative. It's more computational. And …so I think that there needs to be a change in that.