Six Challenges for Educational Technology

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Many exciting applications of information technology in schools validate that new technology-based models of teaching and learning have the power to dramatically improve educational outcomes. As a result, many people are asking how to scale-up the scattered, successful "islands of innovation" instructional technology has empowered into universal improvements in schooling enabled by major shifts in standard educational practices. Undertaking "systemic reform" (sustained, large-scale, simultaneous innovation in curriculum; pedagogy; assessment; professional development; administration; incentives; and partnerships for learning among schools, businesses, homes, and community settings) requires policies and practices different than fostering pilot projects for small-scale educational improvement. Systemic reform involves moving from utilizing special, external resources to reconfiguring existing budgets in order to free up money for innovation. Without undercutting their power, change strategies effective when pioneered by leaders in educational innovation must be modified to be implemented by typical educators.

Technology-based innovations offer special challenges and opportunities in this scaling-up process. I believe that systemic reform is not possible without utilizing the full power of high performance computing and communications to enhance the reshaping of schools. Yet the cost of technology, its rapid evolution, and the special knowledge and skills required of its users pose substantial barriers to effective utilization. One way to frame these issues is to pose six questions that school boards, taxpayers, educators, business groups, politicians, and parents are asking about implementing large-scale, technology-based educational innovations. After each question, I'll respond to the issues it raises. Collectively, these answers outline a strategy for scaling-up, leveraging the power of technology while minimizing its intrinsic challenges.

Question One: ***How can schools afford to purchase enough multimedia-capable, Internet-connected computers so that a classroom machine is always available for every two to three students?***

Giving all students continuous access to multimedia-capable, Internet-connected computers is currently quite fashionable. For politicians, the Internet in every classroom has become the modern equivalent of the promised "chicken in every pot." Communities urge everyone to provide volunteer support for NetDays that wire the schools. Information technology vendors are offering special programs to encourage massive educational purchases. States are setting aside substantial amounts of money for building information infrastructures dedicated to instructional usage.

Yet, as an educational technologist, I am more dismayed than delighted. Some of my nervousness about this initiative comes from the "First Generation" thinking about information technology that underlies these visions. Multimedia-capable, Internet-connected computers are seen by many as magical devices, "silver bullets" to solve the problems of schools. Teachers and administrators who use new media are assumed to be automatically more effective than those who do not. Classroom computers are envisioned as a technology comparable to fire: just by sitting near these devices, students get a benefit from them, as knowledge and skills radiate from the monitors into their minds.

Yet decades of experience with technological innovations based on First Generation thinking have demonstrated that this viewpoint is misguided. Classroom computers that are acquired as panaceas end up as doorstops. As discussed later, information technology is a cost-effective investment only in the context of systemic reform. Unless other simultaneous innovations in pedagogy, curriculum, assessment, and school organization are coupled to the usage of instructional technology, the time and effort expended on implementing these devices produces few improvements in educational outcomes—and reinforces many educators' cynicism about fads based on magical machines.

I feel additional concern about attempts to supply every student with continuous access to high performance computing and communications because of the likely cost of this massive investment. Depending on the assumptions made about the technological capabilities involved, estimates of the financial resources needed for such an information infrastructure vary (Coley, Cradler, & Engel, 1997). Extrapolating the most detailed cost model (McKinsey & Company, 1995) to one multimedia-capable, Internet-connected computer for every two to three students yields a price tag of about ninety-four billion dollars of initial investment and twenty-eight billion dollars per year in ongoing costs, a financial commitment that would drain schools of all discretionary funding for at least a decade. For several reasons, this is an impractical approach for improving education. First, putting this money into computers-and-cables is too large an investment in just one part of the infrastructure improvements that many schools desperately need. Buildings are falling apart, furnishings are dilapidated, playgrounds need repair, asbestos must be removed...otherwise, the machines themselves will cease to function as their context deteriorates. Also, substantial funding is needed for other types of innovations required to make instructional hardware effective, such as standards-based curricular materials for the WorldWide Web and alternative kinds of pedagogy based on partnerships between teachers and tools. (The McKinsey cost estimates do include some funding for content development and staff training, but in my judgment too little to enable effective technology integration and systemic reform.) If most of the money goes into new media, little funding is available for the new messages and meanings that those devices could empower.

Second, without substantial and extended professional development in the innovative models of teaching and learning that instructional technology makes affordable and sustainable, many educators will not use these devices to their full potential. "Second Generation" thinking in educational technology does not see computers as magic, but does make the mistake of focusing on automation as their fundamental purpose. Computers are envisioned as ways to empower "teaching by telling" and "learning by listening," serving as a fire hose to spray information from the Internet into learners' minds. However, even without educational technology, classrooms are already drowning in data, and an overcrowded curriculum puts students and teachers on the brink of intellectual indigestion. Adding additional information, even when coated with multimedia bells-and-whistles, is likely to worsen rather than improve educational settings. Professional development needs are more complex than increasing educators' technical literacy (e.g., training in how to use web browsers). The issue is building teachers' knowledge and skills in alternative types of pedagogy and content, and such an increase in human capabilities requires substantial funding that will be unavailable if almost all resources are put into hardware.

Third, the continuing costs of maintaining and upgrading a massive infusion of school-based technology would be prohibitive. High performance computing and communications requires high tech skills to keep operational and will become obsolete in five to seven years as information technology continues its rapid advance. Yet taxpayers now see computers as similar to blackboards: buy them once, and they are inexpensively in place for the lifetime of the school. School boards rapidly become restive at sizable yearly expenditures for technology maintenance and telecommunications usage—especially if, several months after installation, standardized test scores have not yet dramatically risen—and will become apoplectic if another $50B to replace obsolete equipment is required only a few years after an initial huge expenditure. For all these reasons, investing a huge sum in information infrastructures for schools is impractical and invites a later backlash against educational technology as yet another failed fad.

I would go farther, however, and argue that we should not make such an investment even if the "technology fairy" were to leave $100B under our virtual pillows, no strings attached. Kids continuously working on machines with teachers wandering around coaching the confused is the wrong model for the classroom of the future; I wince when I see those types of vendor commercials. In that situation—just as in classrooms with no technology—too much instructional activity tends to center on presentation and motivation, building a foundation of ideas and skills as well as some context for why students should care. Yet this temporary interest and readiness to master curricular material rapidly fades when no time is left for reflection and application, as teachers and students move on to the next required topic in the overcrowded curriculum, desperately trying to meet all the standards and prepare for the test.

Substantial research documents that helping students make sense out of something they have assimilated, but do not yet understand is crucial for inducing learning that is retained and generalized (Schank & Jona, 1991). Reflective discussion of shared experiences from multiple perspectives is essential in learners' converting information into knowledge, as well as in students mastering the collaborative creation of meaning and purpose (Edelson, Pea, & Gomez, 1996). Some of these interpretative and expressive activities are enhanced by educational devices, but many are best conducted via face-to-face interaction, without the intervening filter and mask of computer-mediated communication (Brown & Campione, 1994).

What if instead much of the presentation and motivation that is foundational for learning occurred outside of classroom settings, via information technologies part of home and workplace and community contexts? Students would arrive at school already imbued with some background and motivation, ripe for guided inquiry, ready for interpretation and collaborative construction of knowledge. People are spending lots of money on devices purchased for entertainment and information services: televisions, videotape players, computers, Web TV, videogames. Many of these technologies are astonishingly powerful and inexpensive; for example, the Nintendo 64 machine available now for a couple hundred dollars is the equivalent of a several hundred thousand dollar graphics supercomputer a decade ago. What if these devices—many ubiquitous in rich and poor homes, urban and rural areas—were also utilized for educational purposes, even though not acquired for that reason? By off-loading from classroom settings some of the burden of presenting material and inducing motivation, learning activities that use the technology infrastructure outside of schools would reduce the amount of money needed for adequate levels of classroom-based technology. Such a strategy also enables teachers to focus on students' interpretation and expressive articulation without feeling obligated to use technology in every step of the process.

Such a model of "distributed learning" involves orchestrating educational activities among classrooms, workplaces, homes, and community settings (Dede, 1996). This pedagogical strategy models for students that learning is integral to all aspects of life—not just schooling—and that people adept at learning are fluent in using many types of information tools scattered throughout our everyday context. Such an educational approach also can build partnerships for learning between teachers and families; this is important because parental involvement is certainly one of the most powerful levers in increasing any student's educational performance.

In other words, unless "systemic reform" in education is conducted with one boundary of the system around the school and another boundary around the society, its affordability and sustainability are doubtful. As a bridge across these boundaries, new media can play a vital role in facilitating this bi-level approach to large-scale educational innovation. For example, videogame players are the only interactive devices widely available in poor households and provide a sophisticated, but inexpensive computational platform for learning—if we develop better content than the mindless follies of SuperMario™ or the grim dystopias of Doom™. My research in virtual reality illustrates how multisensory, immersive virtual environments could leverage learning complex scientific concepts on computational platforms as commonplace as next decade's videogames (http://www.virtual.gmu.edu).

Districts can leverage their scarce resources for innovation, as well as implement more effective educational models, by utilizing information devices outside of classrooms to create learning environments that complement computers and communications in schools. To instead saturate schools with information technology is both very expensive and less educationally effective.

Question Two: ***How can schools afford enough computers and telecommunications to sustain new models of teaching and learning?***

Educational improvement based on distributed learning—utilizing information technologies external to school settings to enable increased interpretive and expressive activities in classrooms—does not mean that schools won't need substantial amounts of computers and communications. To empower project-based learning through guided inquiry, students must have access to sophisticated information devices in schools (Linn, 1997). Even if this is accomplished via notebook computers and wireless networks moved from class to class as required, with pupils also spending significant amounts of time learning without the aid of technology, districts must allocate more money to purchasing, maintaining, and upgrading computers and telecommunications than has been true historically.

Where will educators find the funds for equipment, software, technical staff, ongoing telecommunications services, professional development—the myriad of costs associated with a sophisticated information infrastructure? In the past, this money has come largely from special external sources: grants, community donations, bond initiatives. To be sustainable over the long run, however, resources for technology must come from reallocating existing budgets by reducing other types of expenditures. Of course, such shifts in financing are resisted by those groups whose resources are cut, and district administrators and school boards have been reluctant to take on the political challenges of changing how money is spent. An easy way to kill educational innovations is to declare that of course they will be implemented—as long as no existing activities must be curtailed to fund new approaches. Such an approach to institutional evolution is one reason why, if Rip Van Winkle awoke today, he would recognize almost nothing in modern society—except schools.

Educational organizations are unique, however, in demanding that technology implementation accomplished via add-on funding. Every other type of societal institution (e.g., factories, hospitals, retail outlets, banks) recognizes that the power of information devices stems in part from their ability to reconfigure employee roles and organizational functioning. These establishments use the power of technology to alter their standard practices, so that the cost of computers and communications is funded by improvements in effectiveness within the organization, by doing more with less. If educators were to adopt this model—reallocating existing resources to fund technology implementation—what types of expenditures would drop so that existing funds could cover the costs of computers and communications?

First, schools that have adopted the inquiry-based models of pedagogy find that outlays on textbooks and other types of standardized instructional materials decrease. While these materials are a smaller part of districts' budgets than salaries or physical plants, nonetheless they cost a significant amount of money. When students collect their own data, draw down information across the Internet, and interact with a larger pool of experts than teachers and textbooks, fewer commercial presentational resources are required—especially if learners draw on topical data flowing through information sources outside of schools. Moreover, covering a few concepts in depth rather than surveying many ideas superficially reduces the amount of pre-packaged information educators must purchase.

A second way to reconfigure existing financial resources is to reduce the staff involved in data entry operations. Educators are inundated with large amounts of recordkeeping functions, and one of the most debilitating aspects of this work is the continuous reentry of identical information on different forms. Businesses have saved substantial amounts of money by altering routine information processes so that data is only entered once, then automatically flows across the entire organization to each place in which it is needed. Were educators to adopt these already proven models for cost-efficient information management, the amount of time and staff required for data entry functions would decrease markedly, freeing funding for instruction-related uses of technology.

Third, and on a more fundamental level, teaching is more efficient and effective with new types of technology-based curriculum and pedagogy. At present, substantial re-teaching of knowledge and skills is required; presentational material flows into students' minds, is retained just long enough to perform on a test, and then is forgotten. Class sizes are typically between twenty-five and forty—somewhat too large for effective project-based learning, yet small given that lectures work as well for several hundred students as for several dozen. The scheduling of class periods is too short, limiting teachers and students to fragmentary presentational and practice activities. Teachers all have comparable roles with similar pay structures—unlike other societal organizations, which have complementary staff roles with a mix of skill levels and salaries. Visions presented in the forthcoming 1998 ASCD Yearbook (Dede & Palumbo, in press) depict how altered configurations of human resources, instructional modalities, and organizational structures could result in greater effectiveness for comparable costs—even with the acquisition of substantial school-based technology. This case is also made at greater length in Hunter & Goldberg (1995).

In the commercial sector, too often these types of institutional shifts result in layoffs. However, because of the coming wave of retirements among educators, districts have a window of opportunity to accomplish structural changes without major adverse impacts on employees. Over the next decade, large numbers of "baby-boom" educators will leave the profession, and a staged process of organizational restructuring could occur in parallel with those retirements. Coordinating technology expenditures as an integral part of that larger framework for institutional evolution is vital in districts' planning to afford computers and communications.

Question Three: ***How can many educators disinterested or phobic about computers and communications be induced to adopt new technology-based models of teaching and learning?***

Thus far, most educators who use technology to implement the alternative types of pedagogy and curriculum are "pioneers": people who see continuous change and growth as an integral part of their profession and who are willing to swim against the tide of conventional operating procedures—often at considerable personal cost. However, to achieve large-scale shifts in standard educational practices, many more teachers must alter their pedagogical approaches; and schools' management, institutional structure, and relationship to the community must change in fundamental ways. This requires that "settlers" (people who appreciate stability and do not want heroic efforts to become an everyday requirement) must be convinced to make the leap to a different mode of professional activity—with the understanding that, once they have mastered these new approaches, their daily work will be sustainable without extraordinary exertion. How can a critical mass of educators in a district be induced simultaneously to make such a shift?

Studies of innovation in other types of institutions indicate that successful change is always bottom-up, middle-out, and top-down. The driver for bottom-up innovation in a district is the children. Typically, students are joyful and committed when they are given the opportunity to learn by doing, to engage in collaborative construction of knowledge, and to experience mentoring relationships. That these types of instruction are accomplished via educational technology will excite some kids, while others will be indifferent—but all will appreciate the opportunity to move beyond learning by listening. Educators can draw enormous strength and purpose from watching the eager response of their students to classroom situations that use alternative forms of pedagogy. Often, teachers have shifted from pioneers to settlers because they were worn down by the unceasing grind of motivating students to master uninteresting, fragmented topics; and administrators have undergone a similar loss of enthusiasm by being inundated with paperwork rather than serving as instructional coordinators. The professional commitment that kids' enthusiasm can re-inspire is a powerful driver of bottom-up change.

The source of middle-out change is a district's pioneers. Many teachers entered the profession because they love students of a certain age and want to help them grow—or love their subject matter and want to share its beauty and richness. Often, these teachers feel alienated because the straightjacket of traditional instruction and school organization walls them away from meaningful relationships with their students and their subject. Similarly, many administrators want to serve as leaders and facilitators, but are forced by conventional managerial practices into being bureaucrats and bosses. Middle-out change is empowered when educators who have given up hope of achieving their professional dreams see pioneer colleagues using technology to succeed in those goals—and realize that, if everyone made a similar commitment, no one would have to make continuous personal sacrifices to achieve this vision.

The lever for top-down innovation is the community served by the district. Educators want respect—yet teaching has fallen from a revered professions to a much lower status. The relationship between educators and their community is seldom seen as a partnership; instead, teachers and administrators often feel isolated, forced to perform a difficult task with inadequate resources. Parents, the business sector, and taxpayers bitterly debate the purpose of schools and sometimes attempt to micro-manage their operation. In contrast, when homes, classrooms, workplaces and community settings are linked via new media to achieve distributed learning, much more positive interactions emerge between schools and society. Educators can move from isolation to collaboration with the community, from a position of low esteem to an respected role in orchestrating children's learning across a spectrum of settings. This shift in status is a powerful driver for innovation.

To activate these bottom-up, middle-out, and top-down forces for improvement, educators must take the lead in developing a shared vision for systemic reform, distributed learning, and sophisticated utilization of technology. Making such a commitment to large-scale educational innovation is not only the right thing to do, but is increasingly essential to educators' professional integrity. In many ways, physicians working in health maintenance organizations (HMOs) face challenges similar to teachers and administrators working in today's schools. These doctors are responsible for the well-being of their patients, but work within administrative structures that restrict their decision making capabilities, that are focused on saving money at least as much as on combating illness, and that do not provide the latest technology or much time and resources for professional development. Yet we expect those physicians to do whatever it takes—fight the system for what the patient needs, spend personal time mastering the latest medical advances and technologies—to help those whom they serve. To do otherwise would be malpractice, a betrayal of trust, a breach of ethics as a professional. Given advances in information technology that are reshaping the knowledge students need and the ways educators can help them learn, we need to accept a professional obligation—despite current institutional constraints—to do whatever it takes in changing traditional instructional practices so that a generation of children is truly prepared for the 21st century.

Question Four: ***How do we prove to communities that new, technology-based models of teaching and learning are better than current instructional approaches?***

Few communities are willing to take educational innovations "on faith." Many people are uneasy about whether conventional instruction and traditional testing are developing and assessing the types of knowledge and skills children need for their future. However, most parents and taxpayers feel that the current system worked for them and do not want to substitute something radically different unless new methods are proven to be superior. What types of evidence can educators offer communities that innovative, technology-based models of teaching and learning are so much better—given what our society needs in the 21st century—that the substantial cost and effort of systemic reform is more than worth the trouble?

Research documents that new, technology-based pedagogical strategies result in at least four kinds of improvements in educational outcomes. Some of these gains are easy to communicate to the community; others are difficult—but together they constitute a body of evidence that can convince most people. These four types of improvements are listed below, in sequence from the most readily documented to the hardest to demonstrate.

Increased learner motivation. Students are very excited when exposed to learning experiences that go beyond information assimilation and teaching-by-telling. Guided inquiry, project-based collaboration, and mentoring relationships all evoke increased learner motivation, manifested via readily observable indicators such as better attendance, higher concentration, and greater time on task. All of these not only correlate with increased educational performance, but also are in stark contrast to the attitudes parents and taxpayers formed about most of their schooling. Documenting to communities that students care about what they are learning and are working hard to achieve complex goals is not difficult, given the ubiquity of videotape players and camcorders. Student-produced videos that show learners engaged and excited are intriguing to parents and taxpayers, who may not fully understand what is happening in the classroom, but are impressed by student behavior divergent from their own memories and likely to result in better learning outcomes. Too often, educators take little advantage of this easy way to open a dialogue about instructional improvement with the community.

Advanced topics mastered. Whatever else they believe about the purposes of schooling, parents want their children to have a prosperous lifestyle and know that this necessitates mastering advanced concepts. In the 21st century, being a successful worker and an informed citizen will require the sophisticated knowledge delineated in the national curriculum standards, especially in the sciences and mathematics. Information technology can help students not only to learn these difficult concepts, but also to master the learning-how-to-learn skills needed to keep their capabilities current in a rapidly evolving economy. When shown that technology-based instructional strategies enable teaching sophisticated ideas not now part of the conventional curriculum, more complex than the items on current standardized tests, and harder than what they learned in school, taxpayers are impressed.

Students acting as experts do. Developing in learners the ability to use problem solving processes similar to those of experts is challenging, but provides powerful evidence that students are gaining the skills they will need to succeed in the 21st century. One of the most striking features of a classroom based on new instructional models is that learners are behaving as do teams of scientists, mathematicians, designers, or other kinds of expert problem solvers. Pupils' activities in these learning environments mirror the analytic, interpretive, creative, and expressive uses of information tools increasingly characteristic of sophisticated workplace settings. When parents and taxpayers see students perform complex tasks and create intricate products, they are impressed by the similarity between the recent evolution of their own workplaces and the skills children are developing.

Better outcomes on standardized tests. The most difficult type of evidence to provide for the superiority of new, technology-based instructional models is what communities first demand: higher scores on conventional measures of achievement. Standardized tests are designed to assess only a narrow range of knowledge, and the other three types of improvements just discussed fall largely outside the scope of what they measure. A major challenge for educational assessment is to develop methods that measure a wider range of skills than paper-and-pencil, multiple choice tests, without bogging educators down in complex, time-consuming, and potentially unreliable performance evaluations. Research shows that students' outcomes on conventional achievement tests rise when technology-based educational innovations are implemented, but this does not occur immediately, as teachers and learners must first master these new models of pedagogy. To succeed in systemic reform, educators must prepare communities for the fact that test scores will not instantly rise and that other, complementary types of improvements less easy to report quantitatively are better short-range measures of improvement.

Overall, the single most effective means of convincing parents, the business community, and taxpayers that technology-based models of teaching are superior to conventional instructional approaches is to involve them in students' education. Through distributed learning approaches that build partnerships between schools and society, communities have ample opportunities to observe the types of evidence discussed above, as well as to further enhance students' educational outcomes.

Question Five: ***How can educational technology increase equity rather than widen current gaps between "haves" and "have-nots?"***

Implemented within a larger context of systemic reform, emerging information technologies can produce dramatic improvements in learning outcomes. But won't such educational usage of computers and communications widen inequities in our society? However ample the access to technology students have in schools, learners differ greatly in the amount and sophistication of information devices in their homes and communities. Isn't all this effort simply making education better for the "haves," potentially worsening our society's pathological gaps in income and power? Certainly, new media such as Web TV are dropping in price, and almost all homes have videogames, television, and videotape players—but won't the rich always have more information devices of greater power than the poor, skewing the advantages of distributed learning and increasing inequality?

From an historical perspective, innovative information technologies at first widen inequities within civilization, because initial access to the differential advantage they bring is restricted to the few who can afford the substantial expense of this increased power. As emerging media mature, drop in price, and are widely adopted, however, the ultimate impact of information technology is to make society more egalitarian. For example, the world of universal telephone service is a more equitable environment than was the world of messenger boys and telegraph offices. The challenge for current educational policy is to minimize the period during which the gap between haves and have-nots widens, rapidly moving to a maturity of usage and an universality of access that promotes increased equity.

At present, most of society's attempts to decrease the widened inequalities that new educational technologies could create are centered on access and literacy. In schools that serve disadvantaged and at-risk populations, extra efforts are made to increase the amount of computers and communications available. Similarly, educators and learners in have-not situations are given special training to ensure that they are literate in information tools, such as web browsers. To compensate for more home-based technology in affluent areas, many feel that our best strategy is providing teachers and students in low socioeconomic status areas with additional technology to "level the playing field" (Coley, Cradler, & Engel, 1997).

While a good place to begin, this approach to educational equity is inadequate unless taken beyond access and literacy to also address issues of content and services. The on-line materials and types of assistance that learners and teachers can access must reflect the needs and interests of diverse and at-risk students. For example, I can take homeless people to the public library and show them how to use a web browser to download images of impressionist paintings at the Louvre, but this is not likely to motivate or impress them, since such a learning experience does not speak to their primary needs. Similarly, emerging graphical interfaces such as Microsoft Windows™ enhance many users' capabilities, but adversely affect learners with reduced eyesight who cannot effectively manipulate the visual features of these interfaces.

The real issue in equity is empowerment—tailoring information technology to give dispossessed groups what they want. For example, I worked with a local team of politicians to explore the implications of information technology for improving public services. They were excited about using community-based information terminals to offer improved access to health care, welfare, education, and other social services for the immigrant and minority populations they served. However, when I began to describe how on-line communication tools could help these groups to increase their participation in voting and to form coalitions for political action, the elected representatives immediately lost interest. To truly achieve educational equity, working collaboratively with have-not populations is vital in developing content and services tailored to their needs and designed to build on their strengths and agendas. Otherwise, improving access and literacy will fall short of the success for all students essential to America's prosperity in the 21st century.

<u>Question Six</u>: *If we use technology well, what should we expect as "typical" student performance?*

If we were to implement systemic reform based on new strategies for learning through sophisticated technology, research suggests that "typical" students might do as well as "exemplary" learners do now. Our expectations for what pupils can accomplish are far too low, largely because standard educational processes are obsolete given the progression of information technology, insights into the nature of learning, and shifts in the educational outcomes society needs. In many ways, we live in the "Dark Ages" of schooling—restrained from making rapid advances toward increased instructional effectiveness by outmoded ideas, ritual, and tradition.

Setting our sights higher and using better metrics to measure progress are vital to successful innovation. For example, many people are intrigued by results from the Third International Mathematics and Science Study (TIMSS), which show the United States well behind nations such as Singapore and Japan on math and science outcomes from a globally developed achievement test. Crusaders are implementing reforms to ensure that our students do much better on this test. However, our goal should not be to exceed the level of Singapore on an assessment instrument that, as described earlier, measures only a fraction of what students need to know for their future prosperity—and moreover incorporates a diluted definition of educational quality negotiated across many countries with very different populations and national goals.

Others advocate using a standards-based curriculum as the touchstone for educational effectiveness, and reformers are centering state and national judgments of educational worth on this measure. Certainly, the National Council of Teachers of Mathematics (NCTM) standards are a major improvement over the hodgepodge math curriculum before their inception, as are the American Association for the Advancement of Science (AAAS) standards and similar efforts in other fields. But our metric for whether students succeed should not simply be whether they learn the math mathematicians think is important, the science scientists feel is vital, and so on. Being a productive worker and citizen involves much more than having an adequate background in each field of knowledge. Integrating these concepts and skills and being a lifelong learner with the self-worth, discipline, and motivation to apply this knowledge is of paramount importance—yet not captured by discipline-based standards alone.

New forms of pedagogy are also no "philosopher's stone" that can make golden each educational experience for every learner. Some argue that, if only all classrooms were based on constructivist learning or situated cognition or individualized tutoring or multimedia presentations or integrated learning systems or whatever pedagogical panacea, every student would succeed. However, learning is a very complex and idiosyncratic process that requires, for each pupil, a repertoire of many different types of instruction orchestrated together. In other words, no test, no curriculum, and no instructional strategy in itself can guarantee educational quality—even though our current approach to determining schools' worth is based on these inadequate measures. Instead, we need new standards for a knowledge-based society that combine all these metrics for success and that are based on much higher levels of "typical" student outcomes.

Successful technology-based innovations have the common characteristic that learners exceed everyone's expectations for what is possible. Second graders do fifth grade work; nine graders outscore twelfth grade students. What would those ninth graders be accomplishing if, from kindergarten on, they had continuous access to our best tools, curriculum, and pedagogy? Would they be the equivalent of college sophomores? We are selling short a generation by expecting less and by orienting our curriculum, instruction, and tests accordingly.

Conclusion

My responses to the six questions above sketch a conceptual framework for thinking about the process of scaling-up from islands of innovation to widespread shifts in standard educational practices. These answers illustrate that technology-based systemic reform is hard in part because our ways of thinking about implementation are often flawed. Large-scale educational innovation will never be easy, but can be less difficult if we go beyond our implicit assumptions about learning, technology, equity, schooling, and society. Understanding the scaling-up process is vital for making strategies for change affordable, generalizable, and sustainable.

References

Brown, A.L., & Campione, J.C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), Classroom lessons: Integrating cognitive theory and classroom practice (pp. 229-270). Cambridge, MA: MIT Press.

Coley, R.J., Cradler, J., & Engel, P.K. (1997). Computers and classrooms: The status of technology in U.S. schools. Princeton, NJ: Educational Testing Service.

Dede, C., & Palumbo, D. (Eds). (in press). Learning with technology (the 1998 ASCD Yearbook). Alexandria, VA: ASCD.

Dede, C. (1996). Emerging technologies and distributed learning. *American Journal of Distance Education* **10**, 2, 4-36.

Edelson, D.C., Pea, R.D., & Gomez, L.M. (1996). Constructivism in the collaboratory. In B. Wilson (Ed.), Constructivist learning environments: Case studies in instructional design. Englewood Cliffs, NJ: Educational Technology Publications.

Hunter, B., & Goldberg, B. (1995) Learning and teaching in 2004: The BIG DIG. In U.S. Congress, Office of Technology Assessment, Education and technology: Future visions (OTA-BP-EHR-169). Washington, DC: U.S. Government Printing Office.

Linn, M.C. (1997). Learning and instruction in science education: Taking advantage of technology. In D. Tobin & B.J. Fraser (Eds.), International handbook of science education. The Netherlands: Kluwer.

McKinsey & Company. (1995). Connecting K-12 schools to the information superhighway. Palo Alto, CA: McKinsey & Company.

Schank, R.C., & Jona, M.Y. (1991). Empowering the student: New perspectives on the design of teaching systems. *The Journal of Learning Sciences*, **1**, 7-35.