Appendix B Learning and Teaching in 2004: The BIG DIG

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by

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When we consider the confluence of trends and pace of change in the economy, society, and technology, it is relatively easy to envision systems of schooling, learning, and teaching a decade hence that are very different from those of the past 100 years. It is not clear, however, whether all current educational reform movements are consonant with such a vision.

Our vision of teaching and learning 10 years hence is informed by current and past experiences of technology-using innovators within education, combined with trends outside of the educational system that drive the requirements and opportunities for learning and teaching. One set of external drivers includes global and national trends in economy and demographics (31,32,79). Another set of external drivers includes the rapidly changing information technologies and information infrastructure (11). These changes in the larger society are imposing requirements for change in the skills, knowledge, and learning capabilities of citizens (17, 78, 83). Consonant with the requirements is the trend within education toward constructivist approaches to learning and teaching (65, 80).

Nearly every element of our future vision exists today for some people at some times and in some places. What makes our vision different is the pervasive extent of participation and the seamless interaction of the human, institutional, and technological components. In reality, the shape this convergence of trends takes will be the result of political leadership and policy decisions over this coming decade.

A general theme of our vision is that learning, teaching, and schooling all will have a closer relationship and interaction with people, places and knowledge outside of schools than has been typical in the past 100 years or so (103). The "learners" and the "teachers" are people of all ages, in all walks of life (17, 40). In this vision, every person considers himself both a learner and a teacher. Some people will play a teaching role only part of the time, while others will be employed as professional teachers.

Numerous reports from stakeholders as varied as mathematics teachers and industrial leaders have directed our attention to various facets of this general theme. Most recently, for example, the U.S. Congress, in the School to Work Opportunities Act of 1994, addressed many of the cultural, economic, technological and cognitive factors in its findings:

- three-fourths of high school students in the U.S. enter the workforce without baccalaureate degrees, and many do not possess the academic and entry-level occupational skills necessary to succeed in the changing U.S. workplace;
- a substantial number of youths in the U.S., students of diverse racial, ethnic, and cultural backgrounds, students with disabilities and especially disadvantaged students, do not complete high school;
- the workplace in the U.S. is changing in response to heightened international competition and new technologies, and such forces, which are ultimately beneficial to the nation, are shrinking the demand for and undermining the earning power of unskilled labor;
- the U.S. lacks a comprehensive and coherent system to help its youths acquire the knowledge, skills, abilities, and information about and access to the labor market necessary to make an effective transition from school to career-oriented work or to further education and training;
- students in the U.S. can achieve high academic and occupational standards, and may learn better and retain more when the students learn in context, rather than in the abstract; and
- the work-based learning approach, which is modeled after the time-honored apprenticeship concept, integrates theoretical instruction with structured on-the-job training. This approach, combined with school-based learning, can be very effective in engaging student interest, enhancing skill acquisition, developing positive work attitudes, and preparing youths for high-skill, high-wage careers.

In an increasingly globalized environment, both public and private enterprise must be agile to deal with rapid changes in markets, customer and client, and community requirements. Innovation requires rapid adaptability. Agility must be achieved by a combination of technological and organizational changes. One important change is the delegation of substantial autonomy to reconfigurable, relatively autonomous teams of workers (46). Work reorganization and new technologies propel employees and citizens to take more responsibility, cooperate more with each other, understand their roles in the production system, and act on that knowledge (17, 40, 79). Rather than the predetermined curriculum sequence of the industrial era, people need to learn new subjects and skills at the time they are needed on the job or in civic life.

VIGNETTE: "THE BIG DIG"

We illustrate key elements of our vision through a vignette that takes place in the year 2004 in metropolitan Boston. The Big Dig is a real project. Boston's Big Dig—or Central Artery Tunnel (CAT) project, as it is officially known—is the largest single civil construction project ever undertaken in the United States. A 10-year, $7.7-billion effort, it will include depression of the Central Artery an elevated highway through the heart of Boston construction of a new system of off and on ramps, and the construction of a third tunnel under Boston Harbor. Today, in 1994, the project is scheduled for completion by the year 2004.

The "Big Dig" educational vignette presumes that in the mid-1990s, educators began to build a significant body of exemplary learning resources and activities based upon the Central Artery Tunnel project. Through existing and emerging educational reforms, telecommunications networks, and the evolving National Information Infrastructure (NII), an educational collaborative of teachers and learners of all ages was built.

Vignette Prologue

It's a beautiful spring morning in April 2004. Ten years ago, Massachusetts began its evolutionary effort to restructure the entire way it organized, delivered, and financed education. It's also a special day in Mercedes Banzon's life.

Crossing the street to the Boston Museum of Science, Mercedes reflects on some of the changes she's seen and undergone over the past 10 years. She smiles and shakes her head. Ten years ago, she was "just a teacher"—a self-disparaging phrase she often replied with when asked what she did for a living. Nowadays, in 2004, almost every job involves at least some teaching and a lot of learning. Every industry and public organization now routinely employs teachers. Mercedes recalls one of the most revolutionary aspects of Massachusetts' belief statements of the Goals for the Next Century document: "In the world of the year 2000, there will no longer be possible or desirable the radical separation of civic life, work and continuing education. Education must cease to be an institution, and become instead, a way of life."

Mercedes is now proud to proclaim that she is an "educator." The transformation telescoped in her mind. Ten years ago, she volunteered on a Goals 2000 school/community committee in Dorchester. Today is her first day as Chief Education Officer for the Boston Metropolitan Education Region (BMER). Her visit to the Boston Science Museum will help remind her how all the changes in education over the past ten years have taken root in the lives of students, teachers, parent and community members—in short, everyone.

Mercedes remembers that 10 years ago, teachers and students spent all their time in "school buildings," sealed away from the vital life of learning and information their communities offered. On the other hand, the majority of adults were not a part of the formal educational system and thus had little opportunity to participate in organized learning activities. Advances in communications technology had helped break down some of the walls. That was what first got Mercedes going. As technology coordinator in her school, she worked on a project initiated by the local phone company to start the first school voicemail system in the Boston area. The system enabled parents to more easily communicate with their children's teachers. The next step was a logical one- connecting this phone system with computer dial-up access. At that point, parents could use their computers to access local social service agencies, discover employment possibilities, and enhance their own education. In the late 1990s, businesses in Massachusetts had begun donating and loaning computers to workers and parents as part of a major " lifelong learning" initiative that evolved out of a convergence of federal and state programs. These programs included: Goals 2000, statue and urban systemic initiatives, enterprise zones, and a bipartisan Massachusetts industrial competitiveness effort to make the state more attractive to business and industry.

The creation of the Boston Metropolitan Education Region (BMER) was an institutional outgrowth of these initiatives. Many school system jurisdictions found common ground with the "lifelong learning" initiative proposed by industry-education partnerships and coalitions in the area. The BMER was funded by a combination of these federal, state, industry, and local funds. It is highly dependent upon the CWEIS (Community Wide Education and Information Services) formed in 1994 to take advantage of computer networking in the region.

Mercedes recalls that as its first pilot project, BMER issued a Request for Proposal to students, teachers and community members inviting them to design a nine-week project that would engage all the participants in collaborative projects without regard to the political boundaries of their school districts. Mercedes organized a group of teachers, parents, community center leaders and professionals from health and human services. This group developed a winning proposal and conducted a successful community-wide educational *project called "Using Your Brain," that took advantage of many resources across the area including television, radio, computer networks, and newspapers. This was one of several projects that achieved city-wide citizen awareness of the educational value of many different institutions and groups.*

The Tunnel Team

Mercedes walks through the front door of the Boston Science Museum and sees the brightly colored sign "To the Dig" directing her down the hallway on the left.

Fourteen-year-old Azikwe Jackson-Hu has also arrived early at the Boston Museum of Science this Monday morning. There's a special all-day work session with his Tunnel Team. By 9 a.m. about 30 people have arrived.

The session facilitator is Elaine Corzini, a teacher from the Mather school in Boston. She introduces the goals for today's work—preparing for their Tunnel Team exhibition at Big Dig Week to be held next month. Several thousand visitors are expected at this Boston-wide event. It will also be viewed by many more people through television and computer networks.

To set a high standard and expectations for the Tunnel Team's exhibit, Elaine shows a brief video of last year's exhibition. In it, one team had developed a mathematically interesting analysis of hourly carbon monoxide and temperature readings at several points in the tunnel, over an eight-year period. The large poster display of their insightful charts and graphs had resulted in extensive publicity and, eventually, in improvements being made in the tunnel ventilation systems.

Elaine reminds the group that this exhibition is an important opportunity to get feedback and evaluation for their work on the tunnel project. They need to make careful plans to take advantage of this opportunity to assess their progress in learning.

Although this project team has been working together for many weeks, there are as usual some newcomers at this session. They begin with introductions:

- 20 children, ranging in age from about 10 to 16, who attend three different schools in Boston, Charleston, and Somerville;
- an undergraduate teacher-in-preparation from a local college;
- a graduate student in engineering from MIT;
- an engineer from Bechtel, the Big Dig contractor, and parent of one of the children;
- another teacher from Elaine's school;
- a member of the exhibit staff of the Boston Science Museum;
- a staff member from the Metro Boston Transit Authority (MBTA);
- a faculty member and student from Roxbury Community College;
- a member of the Urban District Assessment Consortium, who specializes in student assessment; and
- also present via video conference are teachers and students from four schools in the Boston area, and Azikwe's mother who is on travel at her company's office in another city.

Because Azikwe's mother has to leave the meeting by 10 a.m., it is agreed that they will begin with the demonstration. Azikwe is impatiently waiting to get started. His mother says,

"Azikwe and I would like to show you some parts of the tunnel simulation and control system that I have been working with as an engineer for the CivTech company. We are subcontractors to Bechtel for tunnel monitoring and maintenance. By the way, Calvin is our contract monitor—Hi, Calvin. Calvin might explain to you later how we managed, after three years of fighting our bureaucracies, to get permission to make this tunnel simulation software publicly available on the network."

While his mother is talking, Azikwe has been operating the computer, getting the tunnel simulation program up on the large screen in the front of the room next to the video conference screen. The teachers and students at the remote locations use a shared workspace tool on their computers so they can see the same computer screen that Azikwe is demonstrating.

She continues, "Azikwe, if you will put the main screen up there, I'll explain the four main components of this system. Then we'll take a look at the structural design part that I use in my work."

About 20 minutes into the demonstration, one of the children asks, "Mrs. Hu, can I ask you a question? How come your tunnel looks really different from *our* tunnel simulation? Isn't this the same tunnel? The only thing that looks the same to me is that the tunnel is made of 300-foot-long tubes."

Azikwe's mother replies, "Meera, you ask an excellent question. Azikwe has shown me your team's tunnel simulation many times, and I know that these programs do look very different from each other. This is because we have different purposes, and are using different software. Your team has been building your tunnel simulation to help you learn and understand and share your understanding of the design principles, and the mathematics and physics needed to understand the design. My program, on the other hand, is used by professional engineers responsible for monitoring and maintenance. So we engineers need different information than you do. Azikwe, would you show the cross-section view again? Notice, for example, that we have much more detail about the electrical system in this cross-section than you would need in your simulation."

Several children, and adults, are now waving their hands for attention. Andy preempts the others. "Mrs. Hu, I have an idea for our exhibition. We could have two screens side by side where we show the differences between yours and our simulation."

Mrs. Hu starts to reply but Jewelle interrupts, "But we can't do that! Her program is too complicated! I don't even know what any of those icons mean up there." She runs over to the screen and points to the icon menu across the bottom.

The community college professor speaks up, "I have some students in my classes who are technicians with the transit authority. They could really sink their teeth into this program. Is it okay for me to introduce it to them?"

Mrs. Hu says, "I think that that'll be okay...I'm sorry, I have to leave for another meeting right now. I'm sure Azikwe will tell me tonight what you decided. If you do decide to work on this, there is a new engineer here on our staff who is just learning this system. He might volunteer to help you learn along with him. Bye, all. See you at the airport at six tonight, Azikwe."

The session suddenly becomes chaotic, exploding with a dozen simultaneous conversations. The teachers and students on the video screen look confused, since they can't understand what anyone is saying. Mrs. Corzini tries to get more discipline into this creative firestorm.

"Let's capture all these ideas in the collaborative notebook, right now," she says. "Make groups of four or five people and enter your ideas into the notebook file Tunnel Session Nine."

About eight small groups form spontaneously, entering their ideas into their notebook computers at the work tables. One of the students gets the collaborative software up on the large screen so everyone can see the emerging comments. Mercedes notices one small group that includes only younger children and asks Lew Girshalt from the MBTA and Ana Julia, a teenager from Somerville, to join them.

The teachers and students at the remote sites join in from their own computers, so everyone can share in the swirl of ideas, exclamations, arguments, sketches.

Here is a sampling of the comments the groups are entering into the collaborative notebook:

"What about our traffic data? We wanted to make a game where people have to correlate traffic statistics with days and times."

"Mrs. Hu's program is too complicated for the younger kids.

"We could connect her tunnel program to our GIS maps of the neighborhood."

"I could help the students ferret out assumptions in Mrs. Hu's model about the structural properties of the tubes and compare it to the one they've been using."

"We were going to videotape the inside of the tunnel and show how to image process a comparison with our simulation."

"We don't have enough time to learn her program before the exhibition. And besides, Azikwe's just showing off."

"Does anyone realize that that system cost the taxpayers two million dollars to develop?"

"That program will not demo well at a public exhibit. The screens are too busy and complicated, the user interface is arcane, we'd need a full-time engineer to handle the booth, who could explain it?"

"We wanted to show the hypermedia we made, where we took that old Big Dig video from 1994 and showed how things really are now, and all the mistakes they made back then."

"We built a model of traffic congestion, and compared the behavior of our simulated traffic jams to real traffic jams in the tunnel. We want to make an exhibit of our program."

Mercedes observes with pride the skills, knowledge, creativity and insight reflected in these spontaneous comments. She walks from group to group, observing the contributions being made by different members of the team. She reflects upon those early attempts at project work 10 years ago. So many of the prerequisite skills-both so-called "basic" as well as metacognitive skills—were simply not present back then, in either teachers or students, so project work was painfully slow and often unproductive. Attention to "basic" skills came first. Clear and concise formulations of what students should know and be able to do-standards—were combined with strong strategies for implementing these ideas within school settings. This prompted more complex assessments and enabled teachers to tie instruction to the diverse needs of their students. Now, even the youngest member of this team has had several years of experience and training in teamwork, investigation, observation, analysis, synthesis, and communication. Even the oldest adult had by now several years' experience in using many computer-based tools including those they used for writing, multimedia creation, data storage and analysis, modeling, communication and collaboration, and many specialized tools for their particular work and pleasure. In 1996, the BMER had recommended a common core suite of tools, and had taken steps to make the software available at very low cost across the area, in all community centers, schools, libraries, homes, government offices. This action was the landmark event that enabled the rapid development of fluency in computer use and information literacy among most people.

After lunch, Elaine facilitates as the group discusses the goals for the exhibit. On the large screen she points one by one to each of the comments made earlier in the collaborative notebook. As the group discusses the merits of each of those ideas, they record these additional considerations.

As Mercedes sits back and watches Elaine's skillful facilitation and recording of the group's discussion, she recalls the BMER meeting four years before when the very contentious issue of scheduling had come to a head in the BMER. It had been extremely frustrating to try to conduct city-wide learning activities that were constantly competing with the rigid class schedules of the separate schools. The separate schools were also at a point of crisis about scheduling because they also were attempting to conduct interdisciplinary project-based learning activities that could not function in the 45-minute class periods. It was at that meeting, while they were recording their discussion in the BMER collaboratory notebook, that they realized the technology they were using could free them from some of the time constraints of their school traditions. Nearly everyone—teachers, students, administrators, many parents—had become fluent in using project databases, collaboratory notebook, videoconferencing, project management tools, people directories. Thus it was now thinkable for people to participate in project teams without having to be physically present at all face-to-face meetings. If everyone would take responsibility to ensure that all project discussions, decisions, materials and products were carefully documented, they could free themselves from some of the tyranny of sched-

ules. So, for example, at today's Tunnel Team workshop only 40 of the 100 members of the team are physically present, another 40 are present via video conference, and the others would have to use the electronic recording to participate vicariously at a time convenient to them. Hence, Elaine's careful attention to the recording of all discussion here at the workshop.

The group decides on four main themes for their exhibition, then divide into four smaller groups to hammer out a plan of work for each of the parts. Mercedes and the other teachers each work with one of the groups. Mercedes' main concern is that each member of the team make a contribution to the exhibition, and that the evaluation plan addresses at least one of the learning goals of each team member. She helps the group address these issues systematically by referring to the electronic records of their learning development plans and the BMER assessment guides.

The experts from MIT, Bechtel, the Transit Authority, and the Science Museum rotate among the groups, serving in their accustomed consulting roles. They are all volunteering their time and expertise for different reasons. The MIT engineer is focusing her graduate studies on new methods of designing supports for underground structures. She is gaining valuable background knowledge through her work with various Big Dig educational teams. The Bechtel engineer, rather than opting for early retirement, has accepted as one of his new job responsibilities the management of the Big Dig education programs. He has been invaluable in helping the team locate data, videos, software, and other historical records of the CAT project's 10-year history. As lead contractor for the CAT, Bechtel also oversees a major portion of the designated educational fund. The Transit Authority technician is working on the Tunnel Team as part of his continuing education program, and is receiving community college credit for this project. All government employees are expected to spend 5 percent of their time in educational activities. While his own learning objectives are in the area of data analysis techniques, he has also been a lively mentor for the children, fascinating them with stories of his work life underground in the tunnel. The Science Museum exhibit designer is working with the tunnel team as part of her official work duties, as the museum is an educational contractor to the CAT project and is the main organizer of the Big Dig Week.

The groups put their draft plans and sketches of the exhibit booth in their Tunnel Team workspace on the network, so that everyone on the team—parents, teachers, students, and other community members—can access and work on the plan.

One of the teachers, the student assessment specialist, and one of the children form a group to review and formalize the evaluation plans. They begin by locating the assessment archives from last years' Tunnel Team exhibitions. They see there were some complaints from parents last year that the evaluators had too narrow a focus and missed some important evidence of the team's creativity and communication skills. They decide to avoid that problem by having two levels of evaluation of the exhibition. They call the two levels "Quick" and "Deep." The "Quick" evaluations will be made by interviewing visitors to the exhibition, who would have unpredictable kinds of backgrounds, skills, and interests but who would represent a wide range of viewpoints. The "Deep" evaluations will be made by a panel of 10 people chosen from the CWEIS school communities' database of teachers and expert reviewers.

In creating the evaluation plan, the group makes links in the database to the individual Tunnel Team students' personal development plans, the Tunnel Team's educational goals, and the emerging exhibit component groups' plans. From these sources, they create packets of background information and draft assessment assignments tailored for each of the 10 panelists. Each panelist is asked to evaluate particular dimensions of the exhibition, depending on their specialty areas—learning, basic competence, communications and collaboration, personal management, information management, mathematics, engineering, inquiry methods, etc. They compose electronic mail messages to the panelists, inviting them to participate, providing pointers to their packets, and requesting a videoconference three days hence to discuss the plan. The student member of the evaluation team takes on the responsibility to coordinate with the panelists and keep all team members informed of schedules and progress.

Just as they are about to finish their work for the day, a group of students and a teacher from Somerville High School appears on the large video screen. “Can we talk about this assessment plan?” they ask.

“Yes!”

The Somerville teacher explains, “We have been reading your draft evaluation plan for the exhibition, and the students have a concern about it. They’ve spent a lot of time the past few weeks learning how to develop this tunnel simulation, learning how to use the simulation authoring tools, and they fear your assessment instructions to the panelists do not reflect this.”

The assessment specialist replies, “I’m not sure I understand you...aren’t the students using the same simulation program that was used by last year’s Tunnel Team?”

“No, that’s our point. When we started this year’s Tunnel Team, some of the students had already learned how to use SimMaker, and they wanted to create their own simulation. Everyone agreed, but this made the project much more challenging than last year’s. Some people have been developing some very important skills in modeling and in mathematics that don’t seem to be reflected in this evaluation plan.”

“Would you then please revise the assessment assignments, and be sure to include a note that you have provided this input to the plan?”

”Sure. The kids and I will work on this tomorrow morning. It will be a very appropriate activity for our modeling seminar, and more interesting than the exercises we scheduled to do anyhow. When the students reflect on how much they have learned, I think they’ll be surprised.”

By 4:30, nearly everyone has left after a productive and exhausting day. Mercedes and Elaine stay a few minutes to exchange some of their observations and concerns.

“Today’s session was productive, but I wish we’d been able to hold it three weeks ago as we had originally planned,” Elaine says. “ I just don’t see how we are going to get everything done in time for Big Dig Week.”

“I know,” Mercedes agrees. “Until today’s meeting, I didn’t realize just how much incredibly rich activity had been taking place in the Tunnel Team this year. These students have enough material for many high-quality exhibitions. I’ve been hearing reports of similar progress from other BMER project groups, like the Harbor Ecology team and the CAT Economics group.”

“I’d like to hear more about those groups.”

“Next week, WBGH airs on national PBS a story about the work of the children, teachers and parents on the ecology of the harbor around the tunnel. A substantial amount of the material used in this television show is based on data, videos, and writings of the students themselves. As follow-up to the PBS story, students in Boston will take people around the world on a vicarious field trip through their simulated tunnel and neighborhood, using video archives from the past six years.”

“What was that you were saying about the CAT Economics group?”

“You might remember that for several years, in a social studies course called “Building Consensus,” students from several Boston communities have been interviewing their parents and local business people to learn first-hand how the project has affected their businesses and how they participated in the Big Dig decisionmaking processes back in the mid-1990s. Today, students are posting on the CWEIS Big Dig forum the results of their interviews with Haymarket pushcart vendors. Their advisor helps them locate a similar set of interviews with Haymarket business people conducted by Globe reporters in 1995, and asks the students to identify, describe and explain differences between their methods and findings and that earlier study.

“Some high school seniors who worked a survey of Haymarket vendors back when they were freshmen are writing their senior project on the economics of the Big Dig. Because they have been working with Big Dig concepts and data for several years, and because they have personal knowledge of many aspects of this project in which they've grown up, it's possible for them to tackle this very complex problem. They've identified all direct sources of funding of the Big Dig construction itself—federal, state, and local governments and private funds—over the past 15 years, and also identified several alternative economic models to use in describing effects on jobs, businesses, industry, individuals and communities. Their work will be evaluated by a team composed of teachers, economists, academic standards specialists, and students, as part of their qualifications for graduation."

"Well, they do have a couple of Harvard and MIT students working on it with them. In fact, I was talking with a world-renown economics professor at Harvard who says this is a precedent-setting analysis of such a large public works project's economics."

"Like the student journalists who stirred up all the controversy last week with their investigation of some politically questionable financial records of the Big Dig?" Elaine grins.

"Adolescents have been stirring up trouble for years about the Big Dig. Students across the city have been publishing a weekly newsletter, *Big Digger,* on the CWEIS. The students' material has contributed to many stories in the Boston Globe and local community newspapers."

The Science Museum staffer reappears, listening to their stories and adding one of his favorites:

"A history class has been studying native American artifacts collected from the Harbor Islands prior to the building of the Harbor Tunnel. They digitized many of the artifacts such as the 3,000-year-old spearhead found at Spectacle Island, and have put these on the CWEIS Web with the guidance of a graduate student archaeologist at a local university. They've been corresponding on-line with several native American historians and students to discuss the dating and interpretation of these artifacts."

"Did you ever imagine the day would come when we would be complaining because our students are doing so well?" Elaine smiled as she said it. "But it's true. We're seeing an explosion in productivity. The ratio of adults to children in the projects keeps growing, now that all the government agencies, social services, and businesses have begun actively encouraging or requiring their clients and employees to show continuing education progress, and the BMER started awarding formal credit for participating in its projects. Now that so many more adults are involved in children's learning, it is not just a few privileged students who get to engage in complex, exciting projects. Nearly every child in the Boston area is spending at least two hours a day in these challenging activities. Many children spend as much as six or seven hours a day because they work from their neighborhoods and homes as well as school. Most rewarding to me is to see the teenagers who now get recognition for their energy, creativity and focus, instead of being thought of as troublemakers."

"Well, there was that gang that built a videogame in which the winner blows up the tunnel," Mercedes sighs, "but two of them got hired away by a videogame company so I guess they're out of our hair for awhile."

A Few Weeks Later . . .

The Tunnel Team teachers, in a videoconference, discuss the evaluation results from the Big Dig exhibition. They are concerned about some weaknesses in their students' mathematical understanding as reflected in their project work.

One member of the teaching team suggests these students need more work with combinatorial properties of patterns and representations of three-dimensional solids.

Another teacher searches the Big Dig learners' task bank. The Big Dig educational task bank has been accumulating over the past nine years, with contributions from teachers, students, parents, professionals in the community, and various educators. The task bank began in 1995 with a grant to the Metropolitan Boston Community-Wide Education and Information Services (CWEIS) for a multi-channel, multimedia educational project. This project launched the educational Big Dig collaborative that has been growing since that time.

She locates three activities that might be helpful. The others look at the activity descriptions on their own computer screens. These are geometry tutorials developed back in the 1980s and they don't take advantage of the dynamic three-dimensional solid modeling tools the students are already accustomed to using. The teachers are not entirely happy with these tutorials, although they agree they are worth trying.

One teacher tunes her network agent to "geometry education," and finds the Geometry Forum at Swarthmore. Live at the Forum at the moment is a small group of high school teachers talking with a researcher in math education.

"Excuse me, may we interrupt for just a few minutes to ask for some advice?" (She types instead of using voice, so she will make a less obtrusive interruption of their apparently informal meeting.)

"Sure. What's up?" they say, using voice.

She introduces herself and her team, and explains their situation.

"Could you point us to a sample of the students' work, and the panel critiques?"

"Sure. Tell your navigator to go to tunnelteam.bigdig.cweis.boston.ma.us."

"OK. We'll take a look later this afternoon and leave you some notes there. I recall a group in the Bay Area of San Francisco was working on something similar with one of the technology labs. We'll check it out for you."

"Thanks! Talk to you soon."

"You're welcome. I assume we may point some other educators to your project?"

"Yes. Our fair use policies are described at the CWEIS home page."

"Thanks. Bye."

The third member of the teaching team, an applied mathematician at the civil engineering firm working for the city, agrees to follow up with the Geometry Forum advice, introduce the Tunnel Team to the new activities, and monitor the students' progress with the activities over the next two weeks.

The Big Dig educational task bank has evolved and accumulated over 10 years. It is a very rich resource, but the quality and appropriateness of the materials for any given situation or learner's needs is variable. Individual teachers often have difficulty identifying task materials suitable for a particular learner or group. For instance, spatial sense, geometry, and visual representations have been focus of renewal in mathematics curriculum since the 1989 publication of the NCTM Standards (64, 90). But even in 2004 it is still difficult to find appropriate learning materials in this area, especially in an interdisciplinary context.

One of the many issues surrounding the task bank—and all materials in the Big Dig distributed information base, including student work—has been the changing rules and customs about intellectual property rights for these materials. Hence the "fair use" policies are explicitly explained in the CWEIS, and each task package includes information about the developers, evaluators, users, and fair compensation policy.

Same Time, at the Community Learning Center

Mrs. Maturana, a recent immigrant from Calí, Colombia, has learned from her daughter that there are jobs available on the Big Dig project. At the community learning center where she is taking lessons in English as a second language, she learns about the jobs databank that is provided by CWEIS. High school students in information systems apprenticeships have been working with the metropolitan Central Artery Tunnel administration to keep the job bank updated. A Spanish-speaking volunteer at the center explains to Mrs. Maturana the different programs available.

Mrs. Maturana is interested to learn more about this, both so she might find a job, and because she would like her high-school age daughter to have such a learning experience.

The volunteer doesn't really know much more about the high school apprenticeships, so she tunes the CWEIS navigator to the CAT administration building. The office building is also a project-based center for high school youth in a school-to-work program for a certain number of hours a day to work on information systems projects. A receptionist appears not to be very busy, so the volunteer asks in voice, “Hello, we’re over here at the Somerville Community Learning Center. Can you tell us about the CAT high school information system apprentices?”

“Oh yes, there are always at least a couple of them around, day or night. I’ll see if I can get one of them to talk to you.”

“Wait. Can you find someone who speaks Spanish?”

“Sure, I think so. Hold on.”

A few seconds later a teen-ager appears on their screen. In Spanish she describes the apprenticeships and the jobs bank.

The metropolitan planning authority, of which the CAT is one part, is working on revitalizing the inner city. It has Big Dig Jobs opportunities created to permit learning to go on simultaneously with the work. So, for example, you might get an unskilled labor job to begin with, and take classes to increase the skills you want to develop. There are opportunities to use these new skills so that you will not be doing menial work without a future prospects once the CAT project is completed.

Mrs. Maturana, still trying to understand all this news about her new city, asks how such a system of working and learning is possible. Who pays for it?

The student explains that his is a joint effort of the city government, private industry, and educational institutions. Industrial firms benefit as well as government agencies. For example, there are some job openings at the plant where concrete sections are made for the underground highway. The workers there are learning a new concrete mold manufacturing technique from the online manufacturers extension service (61).

“Well, Sra. Maturana,” the teenager ends,” I think that you and your daughter Ana Julia should make an appointment to come down to the CAT building. I can help Ana Julia apply for an internship here, while you look for jobs in the database. Let’s find a time next week-I’m here Monday and Wednesday afternoons !”

TEACHING AND LEARNING: UNDERNEATH THE BIG DIG

The Big Dig vignette weaves together many strands of institutional change, learning activities, teacher roles, and technology applications. All these components currently exist in some form in 1994, although they are not yet integrated as widely and deeply into a community as the Big Dig vignette portrays.

Why the Big Dig theme? We use this organizing framework because it helps us think in a concrete way about several elements of reform advocated for education. One set of concepts that can help tie these elements together is embedded in the term “authentic.”

The Meaning of “Authentic”

The notion of authentic instruction is related to our understanding of how people learn. People bring their prior experience and concepts to new situations, and construct their knowledge out of their interaction with the world (4, 12, 65, 80, 91, 102). A community-based scenario such as the Big Dig spotlights the interaction of everyday life and learning. The Big Dig as an educational theme and context, draws on individual and group experiences at home, in their neighborhoods, from their newspapers and television, so that the construction of new knowledge flows naturally from the everyday realities of life.

The CAT project is a very large endeavor affecting in different ways the lives of nearly every person in a metropolitan area. Hence as a theme and context for learning and teaching, it draws upon the real-world experiences of children, professionals, parents, workers and politicians across the diverse neighborhoods of a city. It acknowledges the great diversity of people, and the fact that they bring different backgrounds and experiences to a learning situation(10). Such an emphasis and respect for diversity is a key step to equitable educational opportunity in our increasingly multicultural society. A city-wide context for learning is not the only possible approach to creating a culture of lifelong learning that offers universal and equitable opportunity for everyone. One could, for example, focus on a global context, or on a virtual community of people who share a common interest and background irrespective of their geographic location (11, 82).

Authentic means working on projects and problems of intrinsic interest to the learner or a group of learners, rather than learning what everyone else of the same age is expected to learn at the time; working collaboratively with peers and mentors; closer relationships between people inside schools and outside in the "real world." This cannot be accomplished unless there is a sustained motivation and interest on the part of all the people involved. The CAT project is so large it affects nearly everyone's life. It is multidimensional and of long duration (decades) so that it provides a sustained motivating context. The CAT project involves local, state and national politics, history, ecology, finance, engineering, mathematics, science, social science, journalism, media, business, and jobs.

Authentic means working in a hands-on mode with the physical and social world, in addition to and in interaction with abstract symbols and words, and electronic representations such as television provides. The Big Dig offers a wide variety of places and phenomena for students and teachers to conduct empirical investigations in their own neighborhoods—physical construction, utilities infrastructure, wildlife, vehicle traffic, people's opinions, newspaper and television and radio, historical artifacts. Rather than using electronic media in a way that removes people from their physical and social community, the Big Dig scenario uses electronic media and tools to help reconnect people to their hands-on world. This focus on the learner's interaction with the physical world is important both from the perspective of individual cognitive development and the from the standpoint of the health of the planet.

Authentic means learning something at the time a learner is ready and motivated to learn it—perhaps because it is needed to solve a problem or complete a project, or perhaps just from developmental readiness, or curiosity, or social pressure—rather than in a preset curriculum sequence. This is very difficult for learners and teachers to achieve without the support and accessibility of experts and a large repertoire of instructional materials (12). The combination of the Big Dig and the technological and informational infrastructure provides a set of conditions that make just-in-time learning plausible, if not consistently achievable. In the tunnel team vignette some students needed to advance their skills in mathematics to make progress on their tunnel simulation. The teachers were able to draw upon expertise from national sources (e.g., the Geometry Forum), local industry (applied mathematician from a CAT contractor), higher education, and the CWEIS itself (Big Dig task bank) to create appropriate just-in-time learning opportunities for these students.

Authentic means continual learning. A basic premise underlying our vision is that everyone needs to be learning in our rapidly changing world. Recently, many studies have found far too many adults to be woefully lacking in basic literacy (19). At the same time, highly trained professionals, such as engineers, need constant upgrading of their skills and knowledge.

Authentic learning often occurs in an interdisciplinary context, rather than in separate subjects and isolated topics; working on a problem in depth, rather than covering many topics superficially (3). Thematic, interdisciplinary investigations and project-based learning are becoming more common in schools today. They are usually of short duration and there is not enough time to develop the deep underlying concepts or the skills needed to achieve strong discipline. Therefore many attempts at project-based learning are superficial, lacking in deep understanding of underlying concepts or analytical discipline.

The long duration of a Big Dig theme could provide the years needed to build a coherent interdisciplinary curriculum and repertoire of high-quality learning materials. In the Big Dig scenario, students build an increasingly complex and deep understanding from year to year. A student gathering opinion data from local business people may not have all the skills needed to analyze that data meaningfully in a short project. In the Big Dig scenario, that student might revisit the cumulative data on business opinions the next year, and would then have opportunity to learn more advanced statistical analysis concepts and skills in the context of data with which he already is familiar and personally invested. Because the real world of the tunnel project keeps changing (e.g. perhaps opinions of the market merchants change in a year due to changes in the parking situation), the project could remain fresh and alive—unlike having to repeat a chapter in a textbook (89).

Authentic means working directly with people from other places and cultures, rather than only indirectly through books (85). In today's large metropolitan areas, there are different neighborhoods made up of people from a range of places and cultures. Typically there is little interaction among these separate neighborhoods. A metropolitan-wide theme as encompassing as the Big Dig could be used to provide opportunities and motivation for learning from each other. For instance, students in Cambridge might ask students who live beside the entrance to the tunnel to collect samples of traffic data for their study of the changing traffic patterns over time. With the National and Global Information Infrastructure, students can also reach outside their geographic region for collaborations and resources. The history class studying native American artifacts could correspond directly with native American and indigenous scholars and students around the hemisphere.

Authentic learning often requires teamwork. Different members of the team have different skills, interests, and knowledge to contribute to solution of a complex problem (25). In a context such as the Big Dig scenario, teamwork is natural and logical because the learners bring a wide range of backgrounds and capabilities to the task. Teamwork is becoming more typical in modern corporations and business situations (8, 22, 24, 46). In typical schools of the industrial age, where learners are segregated by age and everyone in a class is expected to be achieving the same educational objectives at the same time, it is difficult to conduct meaningful, complex projects requiring a wide repertoire of skills and knowledge.

In 1990, over 74 percent of women whose youngest child was between the ages of 6 and 13 were working or looking for paid work (58). One might speculate that the best social arrangement for lifelong learning of both the child and the parent is a community-based structure that supports all ages of people in highly flexible ways—including opportunities for adults and children to learn together. "Over the coming years, society's ability to adapt to the changing needs of working mothers and their children will be increasingly essential to the health and vitality of families and to the well-being of their children" (58, p.23).

Authentic means producing something of real value to someone. In our vignette, for instance, students produced a CAT jobs databank that has real value to their parents and others in the community. Other students produced an exhibit that was visited and enjoyed by thousands of visitors. Others produced a newspaper that provided information to many others across the metropolis. The ability of students and teachers to produce knowledge that is of real value to a larger audience is perhaps the single most important change in education, and is the change most directly facilitated through electronic communications technologies and the information infrastructure (70, 81, 96).

Authentic means using the real tools for intellectual work that are used in the workplace, rather than oversimplified textbook techniques. A real context such as the Big Dig could make it possible for educational purposes to draw upon real-world tools such as the tunnel simulation software, the jobs data-bank, data analysis tools, that were developed for work in the community. As we evinced in the Tunnel Team vignette, the tools used by professionals are not the same as, and are not always directly transferable, for use by children or novices. But the existence of and commitment to a long-term project such as the Big Dig would make it feasible to invest the time and effort in learning, modifying, and applying these real-world tools to education.

Authentic means basing assessment of student progress on performance of real tasks rather than artificial tests. In 1994, many groups are working on new methods of assessing student learning as demonstrated in exhibitions and portfolios (14, 21, 43, 54, 55, 56, 59, 60, 61). This has proved to be a very challenging endeavor but as illustrated in the Tunnel Team vignette it becomes more feasible under the circumstances of a large, continuing, and community-wide theme. The hypothetical assessment specialist in the Tunnel Team was able to draw upon previous years' experience, the specialized knowledge of diverse panelists, the voices of learners and teachers, and an accessible base of information about the educational goals of individual learners and teams.

New Roles for Teachers

In all these instances of "authentic" learning, teaching roles are richer and more vibrant than teachers now occupy. Teachers are guides and mentors and learners, rather than mere dispensers of knowledge. The Big Dig is a real-world event that keeps growing and changing, thus it provides opportunities for teachers to continue their own learning. Teachers build a web of contacts in the community outside of schools to which they can turn to help them in their own and their students' learning.

These new roles are already evolving. A 1990s example is the work of Nick Haddad, a teacher in Fairweather Street School in Cambridge, MA, who has been collecting data from the Boston Harbor for seven years. His "Boston Harbor Data Sheet" included weekly statistics on species of fish caught, imports and exports, ships and their cargo, water and air data, and learning activities that integrate the study of the Harbor into schooling. He worked with over 100 teachers from around the city, and with MASSPORT authority experts. He works with a group of teachers from around the city, and with Harbor authority experts, developing educational activities that draw upon these data. His own continuing learning about the changing ecology and technology of the Harbor sustains his motivation for this work.

In 1994 we have many pioneering projects and teachers who have created learning environments that enable students both to develop skills in using advanced technological tools and to apply those skills to the production of valued products for their community (6, 38). For instance, Randall Raymond, a teacher at Cass Technical High School, is Project Director for "Urban Environmental Education in Detroit." Working with businesses, government agencies, community colleges, universities and research institutes in the Detroit region, he has developed community partnerships and outreach programs. These partnerships enable his students to develop skill in applying Geographic Information Systems (GIS) technology to problems and projects of importance to the partners. The students conduct demographic studies for small businesses, perform resource mapping and planning for local units of government, design school transportation systems, develop a complete GIS-driven management system for the entire Detroit Public School system, digitize the Detroit Public Library system, provide GIS training for urban teachers and members of the community, and participate in internships that help make a productive transition from school to work. The students' involvement in local environmental issues has created many opportunities to build and apply skills such as data analysis and spatial analysis.

Information resource facilitator, assessment specialist, technology expert, team manager and facilitator, child development expert, subject matter specialist-all these multiple roles teachers are now beginning to assume must be understood as unfolding within a team environment. Not every teacher need be an expert in each role. What is necessary, however, are changed expectations for, and conditions within, the profession of teaching.

First, the isolated world of the self-contained classroom must give way to a more open learning community in which teachers have a chance to work with, observe and learn from each other as well as from professionals in other fields. These teachers (and their students) will most likely remain with each other over a period of years.

Therefore, just as families will need more power in exercising choices over their children's education, so teachers will need to exercise increased choice regarding whom they wish to teach with and under what conditions.

Second, teachers must be adequately prepared for the new roles they will occupy, not only through academic pre-service education but through significant clinical pre-service experiences as well. Those coming into the profession will need more supervised experience with a group of accomplished mentors than that afforded by present mostly hit and miss induction experiences (26). Project centers such as CWEIS and BMER can function as professional development schools for these prospective teachers.

Third, a restructured teaching profession and workforce will need to be created. This workforce will include people who come to teaching via nontraditional routes (some of the experts in the Big Dig, for example), as well as different incentives for those who occupy differentiated roles. We will return to this point later in the paper.

DISCUSSION: GETTING FROM HERE TO THERE

A new social compact is assumed in the Big Dig vignette. In the interim, what happens to school districts organizationally as technology reduces the need for geographic continuity within a District? In our vignette, the school and district organization is in a transition phase. School districts exist in their traditional form, and they also participate in a metropolitan collaborative based on the CWEIS. This metropolitan collaborative would not have evolved without the concurrent developments in the digital telecommunications infrastructure across the area in the late 1990s. The CWEIS of 1994 had laid the organizational foundation across the city to take advantage of the evolving telecommunications infrastructure. Thus by 2004 the organizational and informational mechanisms for such collaboration were well established. Many community leaders, television and radio stations, businesses, libraries, local governments, universities, and schools were already collaborating on the development of highly distributed information services. Gradually over the mid- and late-1990s these diverse institutions would have developed the technical infrastructure and skills in order to contribute to and benefit from the metropolitan-wide knowledge base.

Mercedes' "Using Your Brain" module could have evolved to the point where the nine-week project module was commonplace across the metropolitan area. Every student might participate in at least one such cycle during the year. Since the projects were designed to produce and not merely "reproduce" knowledge, they were considered "value-added." Communities might find that the projects made good economic and civic sense. Workplace skills were being developed early; the application to real-life examples immediate.

Support for the project cycles came from the Boston Metropolitan Education Region, a quasi-public organization modeled after a metropolitan transit authority or the TVA (Tennessee Valley Authority, a regional organization). Evaluation of the projects were an ongoing concern of the BMER. Now, it was not only students and teachers who were being evaluated; it was also the effectiveness of the various players who collaborated with the students and teachers. What was it that they all agreed was important for students to know and be able to do? How were they to measure it? And what was their own responsibility in seeing to it that adequate resources and opportunities were created to achieve the purposes stated?

With help from the state and federal government, the BMER-supported projects also marked the beginnings of a new approach to educational finance. No longer tied to the property tax, every family is given a base educational "learning account" to apply to a portion of its educational services. This community learning utility is supported as part of the partnership agreement between government and the private sector within the Boston Metropolitan Education Region.

Financing these innovations in learning and teaching and collaboration and knowledge-building might have been a constant struggle over the 10 years from 1994 to 2004. The Big Dig theme could provide a great deal of financial leverage, in several ways. The television, radio, and newspapers invested in the development of a vast array of information and educational material simply because the Big Dig topic was of great interest to their customers. Schools and community learning centers could have built upon that naturally developing corpus of multimedia material. In addition, school students and teachers would have been able to add to the materials because of their first-hand experience with the phenomena. They could have gathered information from local citizens and experts for free through interviews and questionnaires. They could have gather empirical data from the physical construction sites and surrounding areas without cost. Perhaps most important is that the students' work would have value to the community. In 1999 there might have been enough community and school interest in the Big Dig theme for education that they were able to get the CAT authorities to agree to invest 5 percent of CAT funds into education and training.

Is our vision a utopian one? After all, there is nothing new in arguing that technology is soon to exert a profound influence on the institution of schooling. The literature is replete with boastful predictions of major changes that somehow never materialized. What is new, we have argued, is a set of circumstances that make this argument more compelling than similar ones of the past. First, the use of technology within the society is rapidly becoming ubiquitous and necessary for economic survival. Second, the kinds of technologies being developed and deployed are, unlike their antecedents, of a kind that exemplify authentic and "constructivist" approaches to teaching and learning. Finally, the new technologies, especially within the communication field, have already demonstrated the potential to transform the boundaries of teaching and learning.

All this, however, remains speculative. Unlike Lew Perelman's *School's Out* (77), our scenario is not depicting a world of isolated and terminal-bound individuals pursuing an isolated, atomistic vision of "life-long learning." We do not challenge the need for the underlying "social capital" currently being provided for by the institution of schooling. In fact, we believe one of the more serious problems facing contemporary education is the *lack of adequate social capital* (110). That is one reason why we support community-oriented, project-based education with its long period of social and intellectual apprenticeship. We question whether traditional schools, with all their existing social and organizational baggage, can any longer accommodate the profound changes technology is already having on our world while enhancing our children's ability to learn, live, and develop comfortably within it.

The task of public policy, then, is not one of exercising unbridled imagination or passion in pursuit of some technological garden of Eden. Instead, it is a more difficult one—that of sustaining critical public engagement with the present while simultaneously creating incentives that might bring to scale those fledgling developments we decide as a society are most in accord with what is possible and desirable.

Three Contexts For Change

Based on our experience in utilizing technology to transform schools (18, 39), we suggest that there are three distinct but related contexts for change that are critical in transforming the rosy vision we present to one that is attainable. The first context is that of integrating new technology tools and the developing information infrastructure of which they are a part. Second, are issues and challenges associated with incorporating novel approaches to teaching and learning made possible by the new tools and infrastructure. The third context for change concerns the creation of a hospitable political, economic and organizational environment necessary to develop and sustain the visions informing the Big Dig.

Institutionalizing Change: Technology Tools and Information

How to integrate tools and information infrastructure? All the separate technological tools being used in the Big Dig vignette are in use in 1994, although their use today is not as seamless as we portray in the scenario. The first major difference, then, between 1994 and the Big Dig scenario is to be found in the seamless environment of technology and information infrastructures, and the fluency with these tools are used to design and enhance learning experiences.

The *technological infrastructure* includes such components as computers, local area networks, telecommunications, and the equipment that connects all of these to metropolitan, national, and global networks. This infrastructure is just now beginning to change the landscape of American education. Client-server technologies, for example, now make possible decentralized control over the local educational environment. In particular, integration of LANs and WANs, combined with a new generation of servers that are user-friendly, now allow teachers and students to more effectively design and manage their own educational environment.

The *information infrastructure* includes the technological infrastructure plus the information and organizational arrangements that make the educational environment of the Big Dig vignette possible. "Information" is used in its broadest sense, to include such things as:

- the Big Digger newsletter published by the students;
- the 10-year archive of interview data from Haymarket vendors; the database management systems that enable users to create the cumulative archive of interview data;
- the pictures and annotations of the Spectacle Island artifacts on the CWEIS Web; video materials gathered by students on the ecology of the harbor;
- the economic data on the CAT project, and related scholarly papers on economic models being used by the students for their senior thesis; data analysis tools used by the students to analyze and interpret such data as the vendor interviews and the economic data;
- the software and locator directories that make it easy for the Tunnel Team to connect via videoconference with Azikwe's mother's office and the other schools in metropolitan communities;
- the tunnel simulation software demonstrated by Azikwe and his mother; reference data on the various components of the tunnel simulation, such as specifications on performance of materials;the students' tunnel simulation and the simulation-building tools used to create it;
- the shared workspace software tools that enable local and remote participants to observe Azikwe's computer screen during his demonstration;
- the collaborative notebook used for brainstorming and documentation in the Tunnel Team workshop;
- the assessment archives from last year's Tunnel Team exhibitions; the database of expert reviewers willing to participate in assessing student work; students' personal development plans; the Tunnel Team's educational goals;
- the Big Dig educational task bank of lessons and learning activities;
- network agents and intelligent navigational agents that enable the teacher to locate the Geometry Forum; the people and information provided by the Geometry Forum
- the "fair use policies" agreed to by the CWEIS community; and
- the Big Dig jobs bank maintained by high school interns and the city CAT authority.

In our scenario, nearly all of these informational learning components have been constructed through the collaborative efforts of citizens as a byproduct of their learning activities.

In reality, in 1994 there exists very little advanced development efforts that would create and deploy the kinds of resources, tools, and services needed to support the Big Dig vignette. The kind of information infrastructure that is implied and reflected in the vignette is nearly opposite to the kinds of "Information Superhighway" development activity underway in 1994 by the telecommunications and entertainment industries, and other commercial enterprises that control the evolution of the infrastructure. In general, these developments aim towards a view of people as consumers of information rather than producers of knowledge. Funding is practically nonexistent for the development of services, tools, resources, and know-how that would provide the appropriate underpinning for educational experiences such as those reflected in the Big Dig. Every individual project and community has to develop such infrastructures on its own, and none have funding for such purposes, if those services and tools are accessible at all. Localities and states do not fund development of software advances. The federal government has almost no mechanisms at all for funding of software development or deployment in the context of supporting reform of civilian education.

Institutionalizing Change: Teaching and Learning with Technology

Integrating learning tools with an information infrastructure requires a different view of what constitutes a "learning curriculum." The Big Dig participants' information handling, problem-solving, and higher-order thinking skills perhaps provide the most dramatic difference between 1994 and the scenario for 2004. In the vignette, such skills are exemplified in the following ways:

Quality

- the quality control processes built into the student newsletter effort, such that the students' work is usable by professional journalists

Design

- the assessment group's ability to formulate a two-pronged strategy for this year's exhibit assessment, taking advantage of different kinds of input available.

Communications

- the ability of both children and adults to communicate effectively in writing, speaking, and visual media;
- the teaching team's ability to communicate their needs to a distant expert in geometry education; and
- the CAT teenager's ability to explain the organization of the Big Dig Jobs Bank and the institutional context for that effort.

Collaboration

- the ability of people to spontaneously form efficient working teams;
- teacher Elaine Smith's ability to choose the appropriate collaboration tool at the time it was needed for efficient work in the day-long meeting, and the ability of the workshop participants to access and use the tool with fluency.

Analysis

- The high-level analysis skills of teachers and students capable of formulating a comparison between this years' interview data and prior years' study methods and findings;
- A student's ability to envision the usefulness of a side-by-side comparison of two simulation systems representations in the tunnel simulation system;
- A student's ability to conduct a critical analysis of the user interface of the simulation system in relation to the requirements of a large public exhibit; and
- The ability of the Somerville teacher and students to make a quick critique of the draft assessment plan, see it's major flaw, and intervene in a timely manner.

Media

- the students' skill in producing high-quality digital images of the native American artifacts, suitable for publication on the Web and enabling analysis and commentary by distant scholars;
- the high-quality videos produced by students documenting the tunnel and artery traffic; and
- Student fluency with image processing techniques enabling them to conceptualize how to compare current digital images and images from a 10-year-old video.

Information Retrieval

- The ability of the student assessment specialist to locate relevant archives of information concerning individual students, teams, educational objectives, historical assessments, and assessment panelists;
- The teaching team's ability to search the Big Dig educational task bank for materials relevant to the Tunnel Team's needs in mathematics, and to make a quick evaluation of those materials;
- The ability of the volunteer worker at the community learning center to teach Mrs. Maturana how to use the jobs databank, and how to make a live visit to the CAT administration building.

Investigation

- the complexity of the economics project undertaken by the high school seniors.

Learning and Cognition

- A community college teacher's recognition of the utility of the tunnel simulation system for his technician students;
- The engineer's recognition of the similarity between a new professional engineer's learning task and the learning task of a group of schoolchildren;
- A child's ability to envision the use of tunnel traffic data to create an interesting game for adults; and
- A teenager's ability to assess the complexity of the tunnel simulation in relation to the capabilities of her younger teammates.

Science and Engineering

- A teacher's insight about the usefulness of the tunnel simulation for identifying assumptions about structural properties of the tunnel tubes, and her understanding of the value of this activity for the students; and
- A teacher's ability to see how to create a performance test of student understanding of physics by using an operational simulation system.

Yet getting from here to there will not be easy. One of the more difficult areas to address is how to integrate the use of technology in teaching and learning so that it becomes an everyday occurrence in everyone's life.

At present, this integration is the exception, not the rule. More often, as in drill and practice software or traditional ILSes (Integrated Learning Systems), technology is employed to do what textbooks now do. Alternatively, technology is often used exclusively as a "tool" without regard to the quality of the learning it is meant to enhance. In the former instance, the curriculum remains traditional, wed to scope and sequence-oriented subject matter, often with a deadening emphasis on drilling in the "basic skills." In the latter instance, the technology applications can be quite advanced and "constructivist" (email, hypermedia, etc.), but lack sufficient depth of engaging content or context to justify the effort. In both instances, the source of the difficulty is not the technology; it is the curriculum.

Changing the curriculum so that technology can be employed productively is not easy. The national standards movement could prove useful here-providing it results in frameworks that resist dilution and in assessments that resist simplification. Also helpful is widespread interest in the development of project-based curriculum that require teachers and students to orient their demonstrations of learning to significant "out of school" contexts. Emphasis on "school-to-work" transitions might also expedite the kinds of curriculum changes that require a more significant integration of technology.

The unremarkable "ordinariness" of what this technology use might look like in both the content and setting of "real school" is what we attempted to depict throughout The Big Dig. The educational reform efforts of the mid-1990s share a profound shift in emphasis from the content-memorizing paradigm of the past to a paradigm of learning that demands high levels of skill in collaborating, communicating, solving problems, managing information, and the production of knowledge. This has been accompanied by a fundamental rejection of the belief that only a few educated people are required for an industrial economy, to the belief that everyone must be fully educated to participate in a knowledge-based society.

In reality, the Big Dig scenario reflects a high level of cognitive and social functioning with the support of appropriate technologies-a level unlikely o be achieved by 2004. In 1994 there exists almost no research that would lead to the theoretical and empirical knowledge base needed as a foundation for these educational changes. Public monies that currently are being expended in this arena are for deployment and implementation, not research. The Big Dig scenario implies all sorts of understandings that simply do not exist in the current state of the art-understandings of cognition and learning and instruction in the context of very complex, information rich, dynamic situations that have rarely been the context for educational or cognitive research. For instance, currently there is no research on how learners become fluent with image processing or the role of such fluency in novices' development of understanding of dynamic processes (9, 91). There is almost no research underway on appropriate tools for novices' construction of dynamic models and simulations and the cognitive processes involved in such construction. Ironically, at the time local, state and federal education agencies are spending millions to connect schools to the NII and to acquire related computing equipment, there is almost no research on acquisition of information handling skills in the context of very large information space, and their appropriate incorporation into school curricula and practice. Human-computer interface issues such as understandibility and standardization of iconic representations are de facto resolved by software publishers on the basis of idiosyncratic intuitions, with no grounding in empirical research. There is no research underway that would help to inform or establish the kinds of community-wide educational assessment and quality assurance processes and standards reflected in the information infrastructure of the Big Dig scenario.

How inclusive can this ambitious curriculum be? Reviewers asked, will it work for the "bottom half" of teachers and students? This question suggests that there might be a permanent "bottom half." We reject this notion. As Stevenson and Stigler have pointed out in their 1992 comparative study of American and Japanese and Chinese education, the poor achievement level of American students has more to do with our culture of learning than with any presumptive inequities in innate intellectual endowment (92). Setting high standards and expectations for all people, especially in the early grades, instituting a more rigorous and challenging curriculum, and emphasizing "effort" over "ability," will help raise the "bottom half" more than measures whose net effect is to exacerbate, not solve, inequity. In short, there is no reason to believe that there is a permanent bottom half.

Thinkers such as Howard Gardner have pointed out that schools, with their narrow range of individual options and scope and sequence curriculum, often tap into only a limited range of "intelligences" and by so doing, miss the opportunities to engage and develop the talents and proclivities of many students (20).

Authentic Learning: As Opposed to What? Changing the curriculum does not mean that teaching and learning will thereby become effortless. We have been careful not to romanticize learning. When, for example, Azikwe's mother points out to the student Meera that the software program used by professional engineers is different than the students' program, the underlying reason is that the students' program has been created to reflect a controlled learning environment—an environment that is not, nor cannot be, completely "authentic" from the perspective of a professional engineer. Similarly, the utilization of the Swarthmore Geometry Forum by the Tunnel Team teachers is meant to show that there will be times at which specialized instruction (in this case, Geometry) is necessary, though the manner in which it occurs (its "just-in-time" quality, for example) distinguishes its use from traditional scope and sequence pedagogy and curriculum.

Learning is not always fun, engaging, or relentlessly faithful to the real world. It can on occasion require the repetitive performance of tasks or intellectual battle with concepts and theories that are unfamiliar, removed from "reality," even somewhat contrived. That is one reason we believe that paying attention to standards, to what students are expected to know and be able to do, is critical. Unlike past attempts at making education "relevant," contemporary preoccupation with authentic learning is grounded in the belief that there should be explicit habits of mind, competencies and core knowledge that all students are expected to master.

The Tyranny of Time and the "Schedule." What goes on in most schools is often determined by the school schedule (62). Forty-five-minute periods, bus schedules, and rigid work rules imposed by teacher contract, can disrupt the flow of time in which active and engaged learning occurs. Until this changes, it is unlikely that significant numbers of students and teachers will be able to incorporate technologies in a more challenging curriculum. We have already suggested that moving some of the work of schools to outside the school will help free students from the stranglehold of the daily schedule.

But more is needed. In order to make technology an integral and institutionalized part of learning, schools must take seriously the notion that people learn in different ways and at different rates. Arbitrary assignments of students based on age must cease, and more flexible grouping and teaming practices must become commonplace. A central point of our Big Dig scenario is the creative use of computer and communication technologies to help overcome the tyranny of time and the complexities of scheduling group work.

Professional Development: Unless there exists a requisite level of proficiency with (and access to) the various tools and applications, they will not be used at all, much less creatively. Professional development must be continuous; it must have immediate use in instructional contexts; and it must, ultimately, be localized within the learning community. Tools used in professional development must be available for use within the community when and where they are requested.

Phasing in Technology Use: It is not always desirable to begin in a technology-rich environment. Our experience in the Co-NECT restructuring project, in fact, has been the opposite. Unfamiliar technology can have a "smothering" effect on students and teachers. It is often better to phase in its use, so that the instructional, social and physical environments have a developing and organic relationship to one another.

Institutionalizing Change: Politics, Economics and Organization

Communities, Unions and Politics: Who will support the vision? There are a number of different components to this question:

a) **First, what makes us confident that there are enough "experts" out in the community who are willing and able to spend the kind of time with students that the vignette's experts (engineers, public officials, college professors) were willing and able to spend?** In fact, we are *not* confident that this will occur on the scale necessary to realize our vision. To be sure, there will always be a certain number of individuals who happily and selflessly devote their time to education. But we also believe that incentives will have to be created to bring this vision to scale.

Demographics could prove key in making these incentives salient. For example, consider the following demographic projection: While the youth population (10 to 17) is shrinking from 34 percent of the nation in 1970 to 25 percent in 2000, there is a corresponding rise in the over 65 population from 20 million to 40 million during that same period of time (and a rise to 65 million in the year 2030) (31, 32). Healthy and still productive, the over-65 population will most certainly want to extend its stay within the workforce.

From a public policy standpoint, therefore, measures should be considered that might aid in the restructuring of the educational workforce and at the same time, meet projected workforce realities facing corporations, public entities, and institutions of higher education. It is possible, for example, to imagine a new category of "semi-retired" personnel whose benefits remain intact, but whose workloads and salaries are adjusted to allow for civic-oriented contributions, such as becoming educational mentors. A combination of tax incentives and the resultant opportunity to restructure their workforce might prove attractive to both the public and private sectors.

b) **Will teacher unions buy in**? Not likely, given the present political infrastructure of American education. As long as the agenda of local collective bargaining is determined by the existing political and institutional framework of education (school districts, outdated labor law, etc.), there is little likelihood that unions will abandon "hours, wages, and working conditions" as their central purpose or that they will welcome the inclusion of non-dues-paying community experts into their ranks.

At least two changes will have to occur to alter union opposition. First, the political structure upon which union structure is mirrored—e.g., local school districts—will have to be reconceived. And second, there will need to be created positive incentives for unions to change their basic orientation and purpose.

As to the first change, we already see the emergence of alternative political structures within education (such as charter schools and expanded public school choice) as potentially significant developments. These alternatives have begun to exert decentralizing pressure on centralized union rules and regulations as well as school board rules and regulations. Simultaneously, school finance is undergoing taxpayer criticism and extensive review. As states seek funding alternatives to their systems' present reliance on the local property tax, it is conceivable that some of the local focus of economic and political decisionmaking might shift as well. If this occurs, the focus of local unions interest might change. The second change necessary (new incentives) might occur in measures such as providing greater teacher decisionmaking and influence in the area of professional development in return for a relaxation in union determination of "hours, wages, and working conditions," new pay schemes (pay for performance, differentiated pay ushered in through the National Board for Professional Teaching Standards, etc.).

What will happen to school districts as the vision unfolds?

a) **A system of schools rather than a school system**: The organizational context enabling instructional changes like those above, requires less control and more facilitation from the school district central office.

This move toward greater decentralization (school-based management, charter schools, etc.) might, as mentioned, eventually result in a radically different institutional context for education. In the short run, however, increased use of technology in education will raise, as it has done in other areas of government and business, serious questions regarding privatization, the role of middle management and the possibility of decentralized accountability. In general, we believe that schools organized around shared educational visions will be more productive than those that are grouped together on exclusively geographical criteria (30).

b) **Restructure administration**: At least in the near term, school districts will remain the primary administrative organizational agents responsible for schools. If so, much needs to be done immediately to avoid inefficiency at the central office level. Technology planning and implementation is often plagued by archaic central office structures. In particular, facilities, instruction and administrative functions are often maintained by separate line and staff structures.

When this occurs, inefficiency results. Hardware is ordered centrally without regard to the requirements of the applications it will be running; facilities renovation is planned without accounting for the telecommunications or video needs of the local educational program; technology acquisition/maintenance is placed in budget categories and lines that make them susceptible to year-to-year fluctuations in funding, rather than being placed in fixed line items such as utilities.

c) **Integrate administrative and instructional technology**: The history of technology in education has been a bifurcated one: Administrative technology has developed in isolation from its instructional use. Most often, the central office has been the "data processing shop." Instructional use of technology (electronic portfolios, access to databases, etc.) has arisen independently.

Today, it is important to combine these two functions so that: decentralized learning communities have access to information when and where they need it; (health records, budget, car registration, milk count, etc., as well as educational), reporting requirements are made helpful, not burdensome, to these communities; and we avoid the inefficiencies of separate and redundant technology infrastructures.

d) **A school is not a building**: Or at least not the egg crate carton structures that have become identified with school facilities. The new technologies require facilities and infrastructures that can accommodate them. After all, it does little good to have schools equipped for the 21st century but designed for the 19th (insufficient wiring, inadequate, dysfunctional space, etc.). Over half the existing school buildings in the country were built in the 1960s, with an expected shelf-life of 35 years. They were built in a fairly standardized manner and without regard for the eventual inclusion of technology. School districts, especially ones that no longer design schools according to the principle that "one size fits all, " will need help in effecting a transformation (25). The Department of Education and/or private foundations should consider reestablishing a "Educational Facilities Laboratory" (similar to the one created by the Ford Foundation during the building frenzy of the '60s) in order to disseminate current information and promising models of new technology-rich schools. The new "School Facilities Infrastructure Improvement Program" approved by Congress for FY 1995 is a small step in the right direction.

e) **Student mobility**: Another impediment to creating structures that are amenable to sustained flexibility in the learning environment is student mobility, a situation particularly acute in many urban areas. It can be counterproductive for a student to work in a flexible structure that incorporates the creative use of technology, if when that same student moves during the course of the year, her new school incorporates a traditional pedagogical structure and schedule. It is important, therefore, to seek ways in which continuity of educational experience over time persists across traditional attendance boundaries. Increased parental choice, appropriate transportation arrangements and use of networks for continuity of experience from one educational setting to another are examples of the kind of thinking necessary to solve this problem.

f) **Many places for learning**: In our scenario, people are physically located in many different places throughout the city as they participate in learning activities. The technology enables great flexibility of place.

How will this vision be financed? We have already indicated a number of ways in which the financing of elementary and secondary education will have to be reconceived if the vision of The Big Dig is to become generalized. In what follows, we elaborate on these.

How will the teaching workforce be structured and supported? The lion's share of every educational institution's budget is consumed by personnel costs. There are at present some 2.5 million K-12 teachers. By and large, these teachers have been "trained" and compensated as if they were interchangeable parts. The kinds of technology-intensive, project-based education we have sketched will require a fundamental restructuring of the teaching profession. We have already discussed the various new roles that individual "teachers" are now occupying and will increasingly do so. The structure and composition of the workforce as a whole will also experience radical change. More specifically:

- There may be fewer "professional teachers" required. Instead of 2.5 million K-12 teachers, it is possible to imagine a situation in which the profession is restructured to accommodate a permanent "teaching force" far fewer in number. This number would command significantly higher average salaries than at present, meet more rigorous entrance requirements (certification as opposed to simple licensure), and held accountable for student results.

- They might be supplemented with a large number of people who would be paid substantially less. These people (engineers, scientists, writers, artists, etc.) are the experts with whom the teachers and students work directly. As a group, we could expect that these individuals would have their basic health and retirement benefits covered by their existing employers.
- College graduates who attend college on forgiveable loans might constitute a third element of a restructured workforce. Upon graduation, these individuals would be employed as interns in various educational settings. After a number of year's service, the debt incurred from their college loans would be forgiven.
- This restructured three-tiered work force would require significant use of technology. The widespread availability and use of different kinds of technology allows for a more efficient deployment of personnel, greater use of economies of scale, and increased personalization.

How will new organizational structures be created and financed? The Big Dig envisioned the creation of a fictional entity, the Boston Metropolitan Educational Region, as a cooperative venture of local, state and federal government with private industry. If, as suggested, school districts give rise to organizational structures more attuned to out of school learning and common academic purpose, entities like BMER might become typical. These entities could be financed through a combination of various means:

- The expenditure of monies drawn from "lifelong learning" accounts—that is, accounts created and made available to citizens at birth and expended throughout an individual's life by enrolling in any number of various learning/project centers.
- The ability of entities as nonprofit educational corporations to earn revenue by creating socially useful products and/or services, and the leasing of space.
- Industry (biotechnology, finance, software, etc.) support for these entities as training and school-to-work transition centers.

How will space for project-based education be found and financed? A number of possibilities exist:

- **Satellite learning centers**: In Dade County, Florida, a few large businesses built public educational facilities on their premises. By doing so, they have provided many of their employees with an additional benefit and incentive—that of being more directly connected to their children's education.
- **Shared use facilities**: One possibility is shared use of space by constituencies other than K-12. These facilities could be shared, for example, by ongoing community services (such as libraries and other municipal buildings) or corporate job re-training centers.
- **Revitalization of the inner city**: Through measures such as enterprise zone legislation, it would be possible for boards of education to enter into partnership with redevelopment authorities. They might lease and renovate neglected buildings to be used as educational project spaces or cooperative centers by public-private partnerships.
- A federal agency or department (HUD, Department of Education, etc.) or a national foundation might establish a National Educational Facilities Laboratory, whose purpose would be to disseminate best practice and advice on the renovation and construction of new school designs.

How will we organize and finance the research and development needed to make informed use of the considerable technological potential available to us for educational purposes ? What little educational research has been supported over the past 100 years was conducted in a context of incremental improvement of learning, very modest restructuring of learning environments, and minimal use of advanced technologies. Such an enterprise is practically irrelevant to the rapidly changing social and technological conditions at hand. Because education and schooling are seen to be so lagging in the technological change processes underway in other sectors of society, policymakers, decisionmakers and grass-root innovators are totally focused on issues of deployment and implementation at the exclusion of development of a base of knowledge that would enable more rational and cost-effective implementation. Federal agencies are supporting "demonstrations," "systemic initiatives," and "scaling up" activities, rather than accompanying these with a focused quest for understanding and knowledge building.

Given these current political conditions, the only plausible strategy we can think of for supporting the creation of new knowledge and an understanding of learning and cognition in the context of educational technologies and reform is to attempt to do so as a part of implementation projects. Government agency programs that are supporting innovative projects involving learning and teaching and technology could require that some meaningful percentage of the effort be devoted to systematic investigation of learning and teaching processes in the context of their innovations, and to the widespread dissemination of such knowledge. This strategy makes the quest for understanding an integral byproduct of operations and could result in a more secure foundation than is presently being built.

SUMMARY

Technology serves a dual role within education. First, it can be used to support lifelong teaching and learning that is "authentic," and, second, it can catalyze the institutional changes necessary to usher in authentic teaching and learning. The Big Dig reflects both tendencies.

The seeds of technological change have already been planted, and as a result, the system of education as we know it will become radically transformed in the coming years. In particular, we believe that:

The institutional framework of education will shift from an emphasis on "schools" to an emphasis on "communities." The primary functions of schools to date have been custodial and administrative. Economic and civic changes demand that the institutional framework of learning be widened so that these key functions be accommodated. Communities are the natural place to locate this institutional framework.

This trend is already underway. For example, many have argued that it makes more sense to "educationalize" the agenda of social service agencies than to integrate yet another function on top of the academic mission of schools. It is a short step from this argument to one that calls for an integrated community-wide structure that can accomplish all the myriad missions connected with youth (health, employment, etc.). The technology, moreover, is now in existence to effect the communication necessary to make these new structures operationally effective.

The financing of education will shift to an emphasis on "lifelong learning." Everyone is agreed that school finance must change; the question is how? While this will not be easy, the time has come to create lifelong learning accounts. Educational opportunities will be defined to include access to the technologies upon which they will increasingly depend. The origin of these accounts might be initially located within community, regional or state entities.

”Teaching" will be ubiquitous. The role of teachers is already undergoing profound changes, and this trend will continue. Teachers will be integral to virtually every aspect of social and economic life. With the intellectual distance between learning and work disappearing, teaching will no longer be considered an occupation relegated to any one institution. Providing for a continuity in educational experience that is no longer institutionally based, teachers will need to demonstrate technological proficiency in order to accomplish their tasks within a wide variety of settings.

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