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Connecting with the Twenty-First Century: Technology in Support of Educational Reform

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Over the past decade, there have been a number of recognized deficiencies with our current approach to schooling, deficiencies that must be addressed if our students are to be prepared for work and life in the next century (Resnick, 1987). In this chapter we present a vision for twenty-first century education in which these deficiencies are addressed. We present an alternative image of what schools might be like and a set of interlocking social, pedagogical and technological changes that could transform the educational enterprise.

Currently, the emphasis in schools is on individual learning and performance—what students can do by themselves without the aid of other students or external supports, such as books, notes, calculators, and computers. True, from time to time students get to use computers in the back of the classroom and there are occasional group activities but when it comes down to it, students are ultimately judged on their solo performance on tests and assignments. Schools stress the learning of specific facts and generalized principles outside of the context of their use in the real world and apart from the value, needs, or interests that children may bring with them to the classroom. Finally, American schools are organized in assembly-line fashion with the curriculum divided neatly into subjects, taught in predictable units of time, arranged sequentially by grade and controlled by standardized tests intended to weed out defective units and return them for reworking.

This approach to schooling served us well when our production economy demanded a large number of graduates who could read, write, perform simple computations, but most of all take direction from supervisors. But the twenty-first century promises to make very different demands on our students and schools. Economists (Reich, 1991) see a dramatic shift in jobs away from those engaged in production services and toward what are called "symbolic-analysts." Symbolic analysts are problem-identifiers, problem-solvers, and strategic-brokers. They have job titles such as research scientist, engineer, public relations executive, lawyer, consultant, art director, cinematographer, writer, musician, and television producer. Symbolic analysts use a variety of tools and resources, such as computers and scientific and creative instruments, to generate and examine words, numbers, and images. They often have partners and associates and work in small teams. Their work schedules may vary in time and amount, depending on a particular project. The products of their work range from plans, designs, sketches, and scripts to reports, models, and multimedia productions which judged on such criteria as originality, cleverness and the degree to which they solve a problem.

To meet these new demands, students will need to acquire a different set of skills. They will need to be able to use a variety of tools to search and sort vast amounts of information, generate new data, analyze them, interpret their meaning and transform them into something new. They must have the ability to see how their work fits into the larger picture, how these pieces work together, and assess the consequences of changes. They must develop the capacity to work with others to develop plans, broker consensus, communicate ideas, seek and accept criticism, give credit to others, solicit help, and generate joint products.

Making such monumental changes requires coordinated action. This cannot depend on the skills and efforts teachers alone. For change of this magnitude, the community as a whole must elevate the importance of education in everyday life and develop a strong social commitment to and involvement in the educational endeavor that is shared by students, teachers, parents, businesses and community leaders.

Today, schools, homes, and workplaces function separately—connected by geography and circumstances but infrequently by common purpose and collaborative action. But in our vision of communities of understanding, digital technologies are used to interweave schools, homes, workplaces, libraries, museums, and social services to reintegrate education into the fabric of the community. Learning is no longer encapsulated by time, place, and age but has become a pervasive activity and attitude that continues throughout life and is supported by all segments of society. Teaching is no longer defined as the transfer of information, learning no longer as the retention of facts. Rather, teachers challenge students to achieve deeper levels of understanding and guide students in the collaborative construction and application of knowledge in the context of real world problems, situations, and tasks. Education is no longer the exclusive responsibility of teachers but benefits from the participation and collaboration of parents, business people, scientists, seniors, and students across age groups.

How can technology support this transformation? First of all, the Internet is connecting schools with each other and with homes, businesses, libraries, museums, and community resources. The connections between schools and homes will help students to extend their academic day, allow teachers to draw on significant experiences from students' everyday lives, and allow parents to become more involved in the education of their children and to have extended educational opportunities of their own. Connections between school and work will allow students to learn in the context of real-life problems, allow teachers to draw on the resources of other teachers, a range of professional development providers, and technical and business experts. Connections between schools, homes, and the rest of the community will enable students to relate what is happening in the world outside to what is happening in school, will allow teachers to coordinate formal education with informal learning, and will allow the community to reintegrate education into its daily life.

As important as digital information technology is to our vision of the future, we have deliberately avoided the temptation to become speculative about cutting-edge developments. We have chosen to be conservative and limit ourselves to technologies likely to be in wide use early in the next century. Rather, we stress the collateral social change and educational reform that must occur for this transformation to be realized. Where we have been daring is in developing a vision in which these issues have been addressed in systemic and positive ways. When advanced technologies are integrated into a broad effort for school reform, then educators, students, parents, and communities will have a powerful combination that can bring necessary, positive change to this nation's educational system (Means & Olson, 1995).

What we present is not a prediction but a vision of how education might be transformed when technology is coordinated with significant social and pedagogical change. We do not assert that this will happen, only that it can and should. With that introduction, let look at what schools might be like in the twenty-first century.

Characters (in order of appearance):

Steve Early (age 14) and Carmela Zamora (age 15), Falcon learning team members.

Nelson, Steve's 17-year-old electronic pen pal.

Valerie Spring, a senior teacher with a degree in biology.

Sharon Gomez, a mathematics teacher.

George Shepherd, an apprentice language arts teacher.

Noriko Miyake, a science teacher on the east coast; a member of TeachNet along with Valerie.

Christopher Lindsay, a school-work coordinator.

Ms. Lucero, an engineer at the Earth Systems, Inc.

Mr. and Ms. Zamora, Carmela's parents and owners of a small pet store.

Other children, schools, parents, and community members.

Settings:

Most of the events take place in the McAuliffe Learning Center, the physical locus for formal learning, community activities, and social services. McAuliffe is divided into a variety of spaces designed for technology-supported learning. Facilities include learning-team pods with a workstation and project resources; small-group meeting rooms with collaborative technologies and personal interaction devices; and a large multimedia auditorium and performance center. These resources are used by students and teachers during the day and are open to community members at other times.

Scenario: Part One

As he does every morning, Steve Early eats breakfast in front of the TC ("telecommunications computer"). While he watches a news program in one window, his personal communication service relays a video message in another window from his friend, Nelson, who he met at Summer Science Camp. Nelson's vid-message is about a train derailment on a river upstream from the campground where their school groups stayed. "The train caused a hazardous-fuel spill and now endangers the ecosystem along the river." Nelson explains. "I am afraid it will poison the water and hurt the animals." Also concerned, Steve constructs a "scout" agent to search for news clips about the accident, sort them chronologically, and store them on the school server. As he finishes his breakfast, Steve and his parents watch the video that the agent retrieved.

At school, Steve meets Carmela and three other members of their Falcon learning team in the playground. This morning they must present an idea for a project to their teaching team. Carmela heard about the spill too, and she and Steve tell the others about it. "I want to find out what can be done to save the animals along the river, and keep the campground safe." Carmela says. "Let's ask the teachers if we can figure out how to stop hazardous spills from hurting the environment." The other students agree.

In the project planning room, teachers Valerie Spring, Sharon Gomez, George Shepherd and the five students gather around the TC and open their project planning tool. Valerie Spring starts off, "OK, let's fill in the goals for the project. What do you have in mind?" The students chime in with their ideas. "Your ideas sound interesting," Ms. Spring responds, "but what specifically would you like to accomplish with your project?"

"I think we should come up with ways to clean up the mess," says Steve.

"One report said the scientists are trying to figure out normal conditions for the river to help them know how serious it is," another student offers. "Do you think they could use the data we collected at camp? Like water temperature and pH?"

"Good idea," says Ms. Gomez. Always looking for a way to bring math into the conversation, she asks, "Suppose the scientists know how much spilled. How would you calculate the concentration of the fuel in the river, and if the concentration is safe?" asks Ms. Spring.

Carmela puzzles for a moment and then offers, "If you knew the volume of the river you could calculate it. You could test the water to be sure."

"Yea, it might help to look at temperature and pH before and after the spill too," Steve says. "My mom was a camp volunteer, so she has names of other students and schools who were at the camp and would also have data. Maybe she could even be a mentor on our project."

"Let's email them, and counselors who have lists from other summers. We can collect our observations, notes and pictures from our nature walks, and offer it to the scientists!" Carmela shouts. "Maybe they'll tell us more about the damage too, and we can figure out ways to clean up the mess together."

"Great idea," says Ms. Spring. "First, let's plan the project in more detail. Steve, would you like to contact your mother to see if she'd like to work with us on this?" Steve contacts his mother on the TC, and she agrees.

Using their software planning tool, the team and Ms. Early work together to plan the project's organization, timeline, and goals, as well as each student's learning objectives and tasks. As the discussion progresses, the teachers check the goals that students suggest with those listed in the curriculum. The tool lets them see the skills, activities, and subject matter that past projects have emphasized, and each student's learning-history profile. The teachers suggest activities that will help the students gain the skills, knowledge, and experiences identified as absent from their profiles. For example, in the planning tool, Ms. Gomez indicates that the new project will help the students strengthen certain mathematical skills and concepts, including measurement of concentrations, graphing number relationships, and making mathematical connections to real-world problems. She also lists scientific models, skills, and concepts appropriate to the project, including thinking critically about the relationships between evidence and explanations, and understanding ecosystems and organisms. Like most of her colleagues, Ms. Gomez has become adept at thinking in terms of broad, ambitious goal statements established by her school and district.

They decide to first contact the other schools and the scientists to make sure they get the data soon, and make an interactive multimedia report as their final product. "You need to think about your audience for the report," comments Mr. Shepherd, their language arts teacher, "and what they would want to know about your topic." They decide to ask Nelson and his schoolmates to collaborate with them by gathering video and other information about the accident, and to assess the spill's impact and various cleanup methods. They will store their report on the community video server and make it available through the community-access cable channel, and send it the scientists and other schools who contribute data. The report will conclude by taking viewers to the Environment Chat Room on the GlobalNet, where they can talk to scientists, environmentalists, and others about the problem and potential solutions.

Each student has an assignment and downloads the project plan into a personal digital assistant (PDA) with a beginning set of pointers to resources. "I think we could really help here," Steve says. "I can't wait to tell Nelson."

Social Perspective

Connecting learning to home and parents. The National Education Commission on Time and Learning (NECTL, 1994) has identified the limits and constraints of time on learning as a major impediment to educational reform. While efforts to extend time in school are important, a key factor in creating more time for learning will be the extension of learning environments to include home and parents.

American children between the ages of 2 and 11 spend an average of 28 hours in front of the television; teenagers spend about 23 1/2 hours watching TV (Comstock, 1991). Only 29% of American students spend two or more hours a day doing homework (NECTL, 1994). Time spend at home represents a significant resource for student learning. This can be a particularly valuable resource if parents are also part of the picture.

When parents are involved with children's learning—especially parents of students from low-income families and ethnic minorities—students earn higher grades and score better on tests (Henderson & Berla, 1994). Parents expectations become higher for both their children and their schools. Consequently, schools also perform better when parents are involved. It is estimated that when as few as a third of the parents become actively involved, a school as a whole begins to turn around. The performance of all children in the school tends to improve, not just that of the children of those who are more involved. The highest level of student achievement happens when families, schools, and community organizations work together.

The increased pervassiveness and connectivity of technology in the home can increase the involvement of children in out-of-school learning as well as the level of parental involvement. Easy access to technology and rich educational content and opportunities holds the potential to make learning easier, more convenient, more interesting, and more productive. Connections between school and home can pull the child's out-of-school technology use into the context of school learning. It can also make it easier for parents to get involved by accommodating their time constraints and by situating parents' interactions with teachers and their children in the comfortable, familiar context of home experiences and tasks.

In the first scenario, the ready access to computing and its integration with television supported Steve's use of his morning viewing as the origin of a learning project. Connections between school and home allowed Ms. Early and Mr. Zamora to be mentors for their students' projects even though he could not attend the school meetings. Technology also allowed Carmela to bring her project work home in a form that connected to digital data from her father's store. Behind the scenes, technology supports other activities and services that include videotext service and dedicated school video channels that provide continual updates of school activities, video-mail messages that explain student assignments and provide tips for how parents can participate and help, and computer-based assignments, educational projects, and multi-player games that parents can do with their children.

Connecting learning to the workplace and the community. Society is recognizing that students must be better prepared for productive jobs within the competitive world market and that the skills and knowledge for these jobs could be better obtained if academic work more closely resembled authentic work. Reports such as *America's Choice: High Skills or Low Wages!* (National Center on Education and the Economy, 1990) rang the alarm that the United

States is not providing an education that prepares young people for productive careers in the technology-dependent and highly competitive 21st-century work environment.

Work-related learning should expose students to both the practical contexts and the meaningful tasks of adult work as well as the conceptual knowledge and generalizable skills normally associated with formal learning (Schlager, Means, & Poirier, 1993). The teacher plays the important role of guiding the transfer of knowledge between these two areas and helps students reflect on their experiences. At the same time, those members of the community more experience in the practical applications of these skills and knowledge can help students understand how they can be used to solve real world problems.

An important motivation for learning comes from relating events that happen in the larger community to things that are happening in the student's world. The need to understand these events and do something about them can create a context for learning. Connecting the needs, problems, and experiences of the outside world with the formal learning of the classroom makes the knowledge acquired more useful and the world outside more comprehensible.

With this work-related approach, students should be challenged by tasks that:

- Have analogs in adult work, but also reflect students' interests.
- Are complex and open-ended, requiring students to work through the definition of the problem and regulate their own performance.
- Relate to practical situations so that experiences from work and daily living provide important information, strategies, or insights.
- Can be accomplished in multiple ways, typically with more than one good answer or outcome.
- Are performed by student teams, with different students taking on different specialized roles.
- Are performed with the same information and the same kinds of technology tools (though not necessarily identical tools) that are used by professionals.
- Results in a product that allows students to feel that they are making a contribution to the larger community.

Networked communications and collaborative software can be used to support new relationships between the school, the work place and the rest of the community. As reflected in scenarios one and three, teachers, volunteers and experts from various professions can jointly design realistic activities based on authentic tasks that motivate the learning of generalizable skills and concepts. Within this context, teachers provide an overall structure, assess student work and create ways for student self-assessment, and point out linkages between project activities and the concepts under study. Outside mentors and experts can work with students on specific tasks, providing guidance and assistance when students reach an impasse, modeling the way practitioners in the field solve problems and providing guidance that is not associated with the grading process. In scenario three, networking and collaborative software allows students, teachers, and a distant expert to all interact with the same modeling software and jointly come up with a solution.

Scenario: Part Two

Over lunch, Valarie Spring logs into TeachNet, an on-line, nation-wide teacher professional development institute, and enters her virtual office. After reading the messages and fliers stuffed in her door box, she files a position paper that she wrote for an accreditation workshop on Teaching Environmental Awareness in her “public” file cabinet. Using a diagram of the floor plan for the virtual institute, she navigates into the common area, a large space with a community directory, an announcement board, and an event calendar. She consults the community directory to look for a fellow middle-school science teacher, Noriko Miyake, who she met at a workshop several weeks ago. "She usually logs in after school and it's about that time on the east coast," she thinks. Noriko had mentioned working on a hazardous materials project with her students last year, and she may have some helpful suggestions for her and the Falcon team. After scrolling through several screens of login names ("There must be another brown-bag lunch seminar going on in the conference room!” she thinks), she sees that Noriko is in the Planetary Projects Room. She pages Noriko, who invites her to join her, and transports her character there.

“Hi Noriko.” Valarie exclaims over the audio channel, “Do you have a few moments to chat?”

“Sure.” Noriko replies.

Valarie describes their project, and after a short conversation, Noriko suggests that they look at EnvironModel, a virtual reality simulation environment that she used with her students last semester. Earth Systems Inc. developed the simulation to be used collaboratively by engineers in their home office and environmentalists in the field as they plan quick responses to hazardous spills. They developed a modified version for use by teachers and students. With EnvironModel, learners can walk through and experience first hand a virtual spill site--something unsafe in real life. There's an demonstration version of the software in the Curriculum Resources Room. They transport there, launch the simulation in shared mode, and it appears on both of their screens simultaneously.

Noriko opens an example environment, and a 3D rendering of a coastline fuel spill appears on their screens. Norika selects one of the sampling tools and demonstrates how to collect a sample at a particular spot and depth. "This is an important skill, since deciding where and how to sample can vary depending on the type of spill, the environment, and other things. Students learn this by comparing the results they get when they sample in different ways," Noriko explains. "Once you've assessed the damage, you can select one or a combination of several cleanup methods, like fuel-munching microbes, jellies, or photocatalyst-coated micropheres. Where and how to apply them may depend on additional factors like how to minimally disturb surrounding wildlife during the process," Noriko adds. "They have some nice support modules and resource materials on GlobalNet that go with it. Earth Systems also has a resident engineer on their Net site who is available to work with teachers and their classes. It's really a nice service."

"This is great! My students are particularly interested in a recent spill on a river that goes by their Science Camp. Are there example river scenarios, or can we create our own?" Valarie asks.

"Sure, the software lets you customize environments," Noriko says. She shows Valarie how to select from a design palette one of several kinds of environments, chemicals, and sampling tools to render customized learning situations. "Sample environments are provided with the software and also contributed by other teachers, so you may find what you need without creating your own, unless you want to," Noriko points out. "Environments contributed by teachers are kept here in the Example Environments folder, feel free to try some out and contribute your own." Since Valarie's lunch period is almost over, they agree to meet again later in the week after she has had a chance to explore the simulation and some of the sample environments on her own.

Valarie transports to the TeachNet Library to copy a list of environmental project resources for her students. The GlobalNet Science Topic Kiosks, constructed and kept current by the members of TeachNet, are valuable resources for teachers like Valarie. Here she can find more resources that are both "teacher-tested" and mapped onto various State curriculum standards. And, if she needs information that is not in the library, she can consult the librarian or colleagues who are more experienced in the area. The bell rings and Valarie logs off to teach her 6th period class.

Pedagogical Perspective

Project-based learning. In recent years, consensus has evolved around a set of National Education (National Goals Panel, 1994) to improve student learning. By the turn of the millennium, the individual states and local school systems are likely to implement these goals into an extended set of standards that students must achieve. These will serve as a focus for the design of learning environments and activities. Prominent among the National Goals is the objective of increasing student ability to solve problems and demonstrate competency over challenging subject matter, particularly in mathematics and science. In our vision, the "learning project" is the mechanism used to accomplish these goals.

Project-based learning involves students in the identification of some problem or goal of personal or group interest and the generation of activities and products that will accomplish the goal or solve the problem (Blumenfeld, et al, 1991). Within this framework, students pursue solutions to nontrivial problems, ask and refine questions, debate ideas, design plans and artifacts, collect and analyze data, draw conclusions, and communicate findings to others. Because they bring problems in from their own personal lives, students are more motivated to pursue a deep understanding of a cluster of topics across related domains. This approach contrasts with the current practice of superficial coverage of many topics in a single domain.

The project is also a way of valuing and integrating knowledge from multiple perspectives and multiple disciplines. Naturally occurring problems are not compartmentalized into mathematics, science, and language arts. Furthermore, problem solutions benefit from the multiple expertise, perspectives, and modes of expression that come from multiple members of teams—both teams of students and teams of teachers. No one person is likely to have the solution to complex, real-world problems, and differences among students in expertise and experience are valued.

Project-based learning, particularly projects that emerge from student-identified interests, makes planning and accountability more complex. The challenge for teachers is to begin with these student-generated interests and guide the development of a particular project to make sure that students are challenged and that they accomplish important educational objectives within the curriculum. They must build on individual strengths and accommodate the individual needs of students within the group. In addition, they must work with students to generate productive activities and provide them with access to useful resources.

Technology can help both teachers and students manage the complexities of project-based learning. In scenario one, teachers and students use project software to help them identify goals, make plans, and keep track of student progress. At the same time, teachers use curriculum software to see what students have already accomplished, identify individual student needs, and assure the curriculum goals are embedded in the project. Students pursue their projects using software tools of the sort used in the real world. Finally, both teachers and students can use the environment to share experiences and resources with others.

Scaffolding. "Scaffolds" are external aids that provide cognitive and social support for people new to a task or knowledge domain, much as scaffolds on a construction site support workers and materials while a building is erected. These external aids consist of questions, prompts, or procedures provided to students that more knowledgeable people have internalized and provide for themselves. By performing part of the task, scaffolding allows students to manage tasks that are more challenging than the ones that they could do on their own (Vygotsky, 1978). When these aids are a normal part of the classroom discourse, students can model these skills for each other and get assistance from the teacher and others in the group (Brown and Palincsar, 1989). As students refine and internalize these new skills, the supports are gradually withdrawn and students perform more of the task on their own.

Problem solving and critical thinking are particularly challenging curricular goals for young students. They must learn to analyze problems and specify goals, identify information and plan activities that will help them solve the problem, identify the products of their work and specify criteria that will be used to evaluate them, and work as a team to accomplish their goals. The use of scaffolding helps students work through these cognitive and social processes. By using these processes repeatedly across projects, students will come to generalize them, take them out to the real world, and apply them to problems they encounter there.

In our scenario, students use a combination of technological and social supports to scaffold their problem solving. They use a computer-based project tool along with the guidance of teachers and each other to design and manage their project. The tool and the teacher team scaffold students' work by stepping them through the planning process, asking them to define their goals, prompting them to select activities to accomplish these, guiding them to resources, and structuring their assessments. Students begin to use these prompts socially with each other, and ultimately the skills become internalized and they can use them on their own as well as with others. While students work on their project, the tool keeps their goals and plans visible so that they do not lose track of them while in the thick of their activities.

Scenario: Part Three

Several weeks later, Valerie has worked with her colleagues at McAuliffe and Ms. Lucero, the engineer who works with schools using EnvironModel, to create a model of the spill. Earth Systems' western office was grateful for the students' data, which sped up the analysis and cleanup process. In return, Ms. Lucero is working with the Falcons to assess cleanup methods. During this session, students are coached by Valerie, school-work coordinator Chris Lindsay, and math teacher Sharon Gomez. Chris connects their TC with Ms. Lucero. The students use the school version of EnvironModel, which has the basic features of the professional version but runs on less powerful and less expensive computers than the one in Ms. Lucero's office. However, the two machines are connected so that the model appears on both screens and can be altered by both the students and Ms. Lucero. The students are wearing special glasses that enhance the 3D lifelike effect of the environment.

Ms. Lucero's image appears on the screen in a small window beside the large window displaying their model. Back in her office, she uses her stylus to select some photocatalyst-covered microspheres from the cleanup palette and sprinkle them on the spill. She speeds up the clock and they all watch as the spheres become coated with the fuel and convert it to carbon dioxide and water. A graph shows how long it takes and how much of the fuel is cleaned up. "How does this compare to other methods you've tried?" Ms. Lucero asks. "Your report should compare methods in terms of disturbance to the wildlife, speed and thoroughness of the cleanup, and cost and ease. You might find that a combination of methods is best." The team discusses these and other issues with Ms. Lucero and the teaching team. At the end of the session, each student uses a PDA to record information and a reflection on the day's activities in a "learning log." Meanwhile, as they work with each learning team, the teachers use their PDAs track new skills the students have demonstrated and their impressions of how well the exercise fosters collaborative skills.

"OK, team," Ms. Gomez announces, "everyone please make a note in your PDAs to show your parents the model and get their comments on relevant factors and ones that we may have overlooked. Remember, part of the scientific process is presenting a coherent argument to your audience and incorporating their input."

"You present your report in two weeks, so you should choose an approach by the end of the week," Mr. Lindsay reminds them. "Remember, we've invited communities near the spill site and schools and families who contributed to watch the report. Ms. Lucero will also be joining us, so you need to be sharp."

That evening, Carmela shows her parents their model. "I'd like to know more about the animals in the area to help me weigh cost versus thoroughness." Mr. Zamora says. "You've shown me information on the kinds of animals, but not on the food chain. If some plants and insects die, could that cause seemingly unaffected animals to die indirectly by starvation?" Ms. Zamora reaches for the family PDA and calls up the animal diet database they use at their pet store. "Let's link these data to your classroom database, like this, too." They look over the data and sketch out a food web that Carmela can show her class tomorrow, and incorporate into their report.

"Dad, will you mentor our next project?" Carmela asks. "The kids want to learn about reptiles and raise one, and you've worked with them at the pet store."

"Sure, let's send email to your teachers asking how I can help," he says.

Technological Perspectives

A broad range of technological tools will be available to support learning and connect it to the experiences, resources, and people in the outside world. We have selected three areas on which to focus—integrated personal communication services and agents, simulation and virtual reality, and virtual places and collaboration.

Integrated Personal Communication Services and Agents. Current approaches for exchanging electronic documents and accessing the Internet assume that users send, receive, and store documents via a single service provider (America Online, InternetMCI, etc.). These electronic services are separate from voice and other information services, creating difficulties and barriers for users. Several trends suggest significant changes that will integrate these services and make them easier to use. For example, telephone companies are increasing the capability of their infrastructure to transmit text and high-quality audio and digital video. Cable providers will likely offer similar services and access to the kinds of databases currently carried by information utilities. They are also putting in place the infrastructure to provide video-on-demand and interactive home shopping, and building the video servers and set top boxes necessary to support these initiatives. Powerful, wireless information appliances such as personal digital assistants (PDAs) will bring computer processing and communications to situations anytime, anywhere, to let learners work on their projects opportunistically, regardless of their location. Support for the integration of all of these services and devices will be provided by networks of fiber, coaxial cables, and wireless communication connecting schools, homes, and offices to each other and to other networks around the world via satellite and microwave.

In our scenario, when Steve checks the personal communication service on his television for vid-messages, he does not leave the television experience and go to a desktop computer to enter a communications mode in a different medium (that is, text). Nor does he have to interrupt his train of thought to log on to an information utility. Similarly, using their PDA's, students opportunistically update their "learning log" with voice annotations, reflections, and pointers to new information that arise during discussions in school and at home, while teacher's use their PDAs to track skills as students demonstrate them. The integration of services frees the cognitive capacity normally used to operate different systems and allows a deeper engagement with the ideas contained in the documents.

As a result of service integration, the amount of information and the number of people available on the network will increase dramatically. Tools will be needed to make these resources useful and usable. Programmable information-seeking programs—often called agents—will decrease the difficulty of finding and using resources. Collaborating with the user and with other agents, they will automatically performing functions such as searching, collecting, organizing, and distributing information to certain people at certain times. Such agents can be instructed directly, or trained by example—a software agent monitors a user as he or she performs a task, forms a model of what the user is doing, and offers to carry out the actions in the future once it is "confident" that it understands the process (Maes, 1994). In the first scenario, Steve constructs his own agent to search for and organize information about the accident on the GlobalNet. Construction of this agent is easy because these are the kinds of things Steve usually does with information, and the agent knows that.

<u>Simulation and Virtual Realit</u>y. The opportunity to model a phenomenon offers students a significant new way to represent and operate on their understanding of the world. By manipulating and explaining dynamic models, they come to understand system relationships and uncover strengths and weaknesses in their understanding. Emerging advances in simulation technology and computational power will enable new types of teaching and learning, such as situated learning via immersive virtual reality (VR) and distributed simulations that create an illusion of three dimensional space. Computational power and speed has been quadrupling every three years while prices drop by half, suggesting that classroom computers will have enough power to render and manipulate the detailed graphics such simulations require at speeds greater than those afforded by today's dedicated graphics workstations. Advances in VR devices (e.g., special glasses, displays, hand-held wands) will enhance the lifelike effect of the environment and let learners collaboratively interact with the simulation. Using such immersive, multisensory virtual realities, students and teachers will be able to conduct activities in and construct new understandings of a range of systems that were impossible (or unsafe) to experience before—from studying virtual spill sites to reconfiguring virtual DNA molecules and exploring virtual galaxies (Dede, Salzman, & Loftin, 1996).

In this scenario, the students and teachers create a virtual spill site using “smart objects” from the design palette that “know” how they can interconnect, and “know” about properties of the world in which they operate. The students “walk through” a site to assess the damage and collect and analyze samples, and apply and evaluate cleanup methods. Thus, the technologies that support modeling constitute a learning environment that involves students in a systematic process of recursive design—a process that requires them to construct a grounded understanding of science and math while simultaneously developing a mental model of systematic inquiry.

Virtual Places and Collaboration. Currently, researchers are focusing a great deal of attention on workgroup computing, also known as computer-supported collaborative work environments. These are hardware and software environments that connect people, perhaps at different sites, to work on shared tasks. They scaffold collaborative problem solving and design by allowing users to exchange and work on shared mutltimedia documents, in synchronous or asynchronous mode. Computer-supported cooperative learning environments are just beginning to spin out of these technological developments (Cockburn & Greenberg, 1995; Pea, 1994). Developers of next generation collaborative work technologies are employing a particular technology called graphical multi-user virtual environments (MUVEs; Roseman & Greenberg, 1996; Harrison & Dourish, 1996). These “place-based” environments employ a spatial or building/room metaphor to organize and enable social relationships and interactions in a distributed environment. Text-based professional and educational MUVEs have existed for years (Bruckman & Resnick, 1993), but emerging technologies are enabling the addition of audio, video, shared applications, and shared gesturing to these environments.

In our scenario, Ms. Spring works via TeachNet with a distant colleague who introduces and demonstrates a modeling environment useful to the project. She can also attend formal events (like inservice workshops), and informal ongoing activities (like teacher collaboratives) in the environment, and access standards-based resources used by her TeachNet peers. In this way, teachers can employ collaboration environments to sustain and enrich professional discourse, while gaining access to greater numbers of educators. Similarly, the students collaborate with an expert who can see and manipulate the virtual spill site that the students are exploring. The students can hear her and see what Ms. Lucero is doing, and work together on its development. Ms. Lucero collaborates with students to solve special problems their teachers do not have the expertise to tackle, and collaborates with their teacher to create an authentic task and experience for the students. These capabilities enable new kinds of relationships, new levels of participation, and new activities that support learning.

Discussion

If the vision that we present is to be realized, a number of corollary social changes must take place along with the development of advanced technology. As mentioned above, education must become a more central focus of the community and innovative pedagogical practices must become common place. These changes will both support and be supported by technological resources as they become widely available. In addition, we have two other concerns that are more immediate:

teacher training and equity of access to technology. Addressing these concerns are the necessary first steps toward a vision of technology and education reform in the 21st century.

Connecting teacher training to a community of practice. To fulfill our vision, teachers would need to learn not only to use the various technologies described in our scenarios, but also to design, structure, guide, and assess progress in learning centered around student projects. Teachers need to help students design projects that will incorporate important content. Teachers must be able to help students overcome impasses encountered in their work without dominating the group process. Teachers need to be comfortable letting their students move into domains of knowledge where the teachers themselves lack expertise and they must be able to model their own learning process when they encounter phenomena they do not understand or questions they cannot answer. Teachers need to work with other teachers and other professions to coordinate resources and services. Teachers need to be creative in finding ways to embed measures of student understanding within group projects—no easy task when multiple groups are working concurrently and different students assume different roles within their groups.

This new role for teachers is challenging and requires a very different approach to teacher professional development. New approaches posit that to support significant change, teachers must engage in sustained training and create membership in a broader community of professional practice (Little, 1993). Typical summer institutes for teachers do little to alter the isolated and isolating character of classroom teaching. Too often, teachers returning from them have little chance to implement what they have learned and make significant changes to ongoing practices in their home schools. Ongoing, collaborative approaches to professional development help establish a professional culture that creates self-expectations among teachers that they will be studying some aspect of practice, comparing notes on implementation, seeking new ideas, and help each other out.

As collaborative technologies become more widely available, they will support this culture of sharing and continuous professional development. In scenario two, Valerie finds a valuable resource in her colleague, Noriko. However, Noriko is not the teacher next door (although these teachers are also collaborators in Valerie's work) but on the east coast. The virtual places collaborative environment allows these two teachers to meet at a mutually convenient time, access a rich resources, and work together on the same materials.

Equity and access. The biggest assumption in our scenarios is that students and their families will have near-universal access to high-end technologies. As technology connects learning environments and homes, it becomes increasingly important that differences in socioeconomic status not create an electronic form of school segregation between the technological haves and have-nots. Government and school programs and regulations will need to assure the accessibility and affordability of at least a minimum form of network service for all homes.

Although the growth in the number of computers and video- based technologies in schools has been exponential (Office of Technology Assessment, 1995), the number of hours per week that individual students have access to technology is still very low in most schools. Moreover, those schools serving children from economically disadvantaged homes have less access to technology than do those serving more affluent communities and, when they do have access to computers, are less likely to use them in ways other than drill-and-practice (DeVillar & Faltis, 1991). In some states, school budgets are stretched so tightly that students must share basic texts; under such circumstances, teachers have a hard time building enthusiasm for learning to use new technologies.

There are positive signs, however, that the issue of equity is getting more attention. School financing mechanisms that leave areas with low property values with very limited per pupil educational funding are being challenged successfully in many states. Federal programs are supporting the acquisition of technology and implementation of parent involvement programs as part of the effort to improve the educational prospects for children at risk of school failure. Corporate support for education programs, particularly programs that incorporate technology, is at an all-time high and is likely to continue. The business community has become much more aware of its dependence on a well-educated workforce and of the changing cultural, gender, and ethnic composition of that workforce. Many corporations are making a particular effort to reach out to schools serving large numbers of children from less affluent homes, where computer technology is usually absent.

The concentration of resources for technology in schools serving larger proportions of children from low-income homes will not bring real equal opportunity, of course, if the students do not have the same kinds of home resources used by other students and their caregivers. Without something approaching universal access and perhaps special rates for low-income households, we will not see the kind of across-the-board parental participation described in our scenario. Another way to make technology accessible to parents is to make school equipment and services available during non-school hours. The McAuliffe Learning Center of our scenario has a technologically and socially rich community center. The co-location of community groups, social services, and educational programs can increase the impact of these services and increase their efficiency. Making these resources available to parents and students during non-school hours can further increase impact and reinforce educational goals. As a place where parents and children come together to engage in learning activities, the learning environment can become the center for building communities that learn together.

References

Blumenfeld, P.C., et al., (1991). "Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning," *Educational Psychologist* 26(3 and 4), 369-398.

Brown, A. & Palincsar, A. (1989). "Guided, cooperative learning and individual knowledge acquisition." In L. Resnick (Ed.), *Knowing, learning, and instruction* (pp. 393-452). Hillsdale, NJ: Erlbaum.

Bruckman, A. & Resnick, M. (1993). Virtual professional community, results from the MediaMOO Project. *The Third International Conference on Cyberspace*, Austin, TX. Available FTP: Hostname: media.mit.edu Directory: pub/asb/papers/ File: MediaMOO-3cyberconf.txt.

Cockburn, A., & Greenberg, S. (1995). TurboTurtle: A collaborative microworld for exploring Newtonian physics. *Proceedings of the First International Conference on Computer Supported Cooperative Learning (CSCW 95)*, October 1995, Bloomington IN, pp. 62-66.

Comstock, G. (1991). *Television and the American child*. San Diego, CA: Academic Press.

Dede, C., Salzman, M., & Loftin, B. (1996). The development of a virtual world for learning Newtonian mechanics. In P. Brusilovsky, P. Kommers, and N. Streitz, Eds., *Multimedia, Hypermedia, and Virtual Reality*.

DeVillar, R.A., and Faltis, C.J. (1991). *Computers and Cultural Diversity: Restructuring for School Success* . Albany, NY: State University of New York Press.

Henderson, A.T., and Berla, N. (1994). *A New Generation of Evidence. The Family is Critical to Student Achievement* . Washington, DC: National Committee for Citizens in Education.

Harrison, S. & Dourish, P. (1996). Re-place-ing space: The roles of place and space in collaborative systems. In *Proceedings of the Conference on Computer-Supported Cooperative Work* (pp. 67-76), New York: Association for Computing Machinery.

Little, J. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis*, 15(2), 129-151.

Maes, P. (1994). Agents that reduce work and information overload. *Communications of the Association for Computing Machinery, 37* (7), 31-40.

Means, B. & Olson, K. (1995). *Technology's role in education reform*. Menlo Park, CA: SRI International.

National Center on Education and the Economy (1990). *America's Choice: High Skills or Low Wages!* The Report of the Commission on the Skills of the American Workforce. Rochester, NY:

National Education Commission on Time and Learning (1994). *Prisoners of time*. Washington, D.C.: U.S. Government Printing Office.

National Goals Panel (1994). *The national education goals report*. Washington, D.C.: U.S. Government Printing Office.

Office of Technology Assessment (1995). *Teachers and technology: Making the connection*. Washington, D.C.: U.S. Government Printing Office.

Pea, R. (1994). Seeing what we build together: Distributed multimedia learning environments. *The Journal of the Learning Sciences, 3* (3), 285-299.

Reich, R. (1991). *The work of nations: Preparing ourselves for 21st-century capitalism*. New York: Alfred Knoff.

Resnick, L. (1987). "Learning in school and out." *Educational Researcher, 16*(9). 13-20.

Roseman, M. & Greenberg, S.(1996). TeamRooms: Groupware for shared electronic spaces. *Human Factors in Computing Systems CHI '96 Conference Companion*, 275-276. New York, NY: Association for Computing Machinery.

Schlager, M., Means, B., and Poirier, C., (1993). "Enhancing Skills Through Distant Mentoring," Menlo Park, CA: SRI International.

Vygotsky, L. (1978). *Mind in Society. The Development of Higher Psychological Processes* . Cambridge, MA: Harvard University Press.

As a founding member of the Partnership for 21st Century Skills, NEA is extraordinarily proud of our partnerships with leaders in education, business, and policy circles to forge a common vision for education that will prepare our young people for college, work, and life. We all believe that every child should possess strong content mastery, as well as the â€œFour Csâ€: critical thinking, communication, collaboration, and creativity. We designed this guide, Preparing 21st Century Students for a Global Society: An Educatorâ€™s Guide to the â€œFour Csâ€, to clarify this vision for classroom teachers and