TECHNOLOGY'S ROLE IN EDUCATION REFORM

Findings from a National Study of Innovating Schools

September 1995

Prepared for:

Office of Educational Research and Improvement
U.S. Department of Education

SRI International

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EXECUTIVE SUMMARY

Educational reform calls for a shift away from organizing instruction around short blocks of time devoted to lecture or practicing discrete skills in specific academic disciplines toward an emphasis on engaging students in long-term, meaningful projects. It is well documented that technology can enhance student acquisition of discrete skills through drill and practice. This study addresses the question of whether technology can provide significant support for constructivist, project-based teaching and learning approaches and the associated issue of the elements needed for an effective implementation of technology within an educational reform context.

Case studies of nine sites that have been using technology in ways that enhance a restructuring of the classroom around students' needs and project-based activities form the centerpiece of the project. In selecting schools for study, we gave priority to sites that have emphasized education reform (rather than technology for its own sake) and that provide challenging, authentic activities for students from economically disadvantaged backgrounds. Eight individual schools and one network of 462 schools constituted the case study sample.

The Vision: Technology-Supported Constructivist Classrooms

The model of constructivist teaching that motivated our research design has student involvement in complex, meaningful tasks or projects at its core. Once a commitment is made to structuring the classroom around such projects, nearly every other aspect of pedagogy must change as well. Projects with real-world relevance will nearly always be multifaceted, incorporating both higher-order skills, such as design, composition, and analysis, and more basic skills, such as the mechanics of writing. They will also nearly always be multidisciplinary in nature and will require extended periods of time to complete. The very complexity of the task will make it advantageous to have students work on them in groups, resulting in a greater emphasis on teamwork and collaborative skills. Heterogeneous roles will tend to emerge as students tackle different portions of the project. Teachers will design the overall structure for project activities and provide the resources that students need to do them, but students will have much more responsibility for their own learning and for producing finished products that meet high standards. Teachers will function as roving coaches, helping individual students or groups over rough spots and capitalizing on the "teachable moment" within the context of the students' engagement in their work. In short, when instruction is organized around complex, authentic projects, there are strong pressures to break away from the discrete academic disciplines, repetitive drill, short periods of instruction, and teacher-led lessons that have been the hallmarks of American education for so many years.

Effects of Using Technology

In our search for appropriate case study sites and in the field research that followed, we found that it is not easy for teachers to implement the reform vision described above. Constructivist, project-based teaching and learning make severe demands on teachers, and adding technology to the mix, at least initially, adds to the intellectual and logistical burdens. Nevertheless, there were teachers at our case study schools whose classrooms demonstrated what can be done when technology and carefully designed project-based activities are used in concert. The teachers we studied who were involving their students in long-term, complex projects supported by technology found that technology supported their efforts by:

- ***Adding to the students' perception that their work is authentic and important.*** Students evidenced greater concern about the quality of their technology-supported work, giving more consideration to how it could be perceived by external audiences.
- ***Increasing the complexity with which students can deal successfully.*** Teachers were often surprised not only by how quickly their students learned to use new hardware and software but also by how much farther they could go in specific subject areas when given technology supports. Technology can both automate mundane, repetitive portions of a task and support visualizing and presenting more essential, abstract elements.
- ***Dramatically enhancing student motivation and self-esteem.*** Case study teachers were nearly universal in citing the positive effects of technology on student motivation. Using technology increased the amount of time students spent on a task, their willingness to critically review and revise their work, and their pride in the finished product.
- ***Making obvious the need for longer blocks of time***. When students used technology to support their project work, it became clear that time for working on project activities needs to be extensive enough so that students can get access to their work files, make significant progress, and then store them for future work.
- ***Creating a multiplicity of roles,*** leading to student specialization in different aspects of technology use. Given the ever-changing array of technology capabilities, students found a wide range of potential specialties ranging from creating hypertext links to navigating the Internet to videoediting to computer graphics. Each of these roles is valuable in a complex project, and students who had not excelled in more conventional academic settings often shone in one or more of these roles.
- ***Instigating greater collaboration,*** with students helping peers and sometimes their teachers. Working side by side on technology-based tasks, students exhibited a tendency

to seek advice and offer it to each other. Teachers reported that a collaborative ethic emerged that often spilled over into non-technology-based activities.

- ***Giving teachers additional impetus to take on a coaching and advisory role.*** When students were actively engaged with technology, the teacher had less need to be giving the whole class information or acting as disciplinarian. Instead, the teacher became a roving coach, working with one group or student and then another. Computer technology further supported this coaching role by providing a readily viewable display of the student's work and the capability for the student and teacher to jointly generate, try out, and evaluate alternative approaches.

Involvement in technology-based educational reform efforts had effects also on the teachers themselves. Although technology-supported classroom projects required a great deal of the teachers' own time, as well as great effort, they paid sizable dividends in terms of the teachers' own professional growth. Respondents talked about:

- ***An increase in their technology and pedagogical skills.*** In addition to learning about the technologies that are incorporated in their classroom activities, teachers acquired skills in setting up cooperative work groups, providing individualized coaching, and orchestrating multiple parallel activities within their classrooms.
- ***Greater collaboration within their own school.*** The introduction of new technologies gave teachers a compelling reason to come together to think about what they were really trying to teach and how technology could support their goals, to learn about new technologies, and to plan multidisciplinary technology-supported projects.
- ***Contact and collaboration with external school reform and research organizations.*** Many technology-supported projects were funded or initiated by outside organizations that worked with the classroom teachers in designing and implementing classroom applications of technology.
- ***Involvement in training and professional conferences.*** Involvement in technology-related activities brought many teachers recognition, not only within their schools but also at state, national, and international conferences.

Implementation Lessons

As challenging as it is to bring a constructivist approach to an individual classroom, there is an equally difficult challenge in implementing a schoolwide reform. Central to this challenge is getting all or most of the teachers within a school to buy into a coherent instructional vision and strategies for using technology to support that vision. School leadership and time and opportunity for joint decision-making and the forging and continual refinement of a common vision must emerge.

Our case study schools were not uniformly successful in implementing a schoolwide reform that brought the constructivist model and technology use to every classroom. But their disappointments and failures were just as informative as their successes. From their experiences, we derived a number of lessons for technology-supported educational reform efforts:

- ***Time must be devoted to developing a schoolwide vision,*** a consensus around instructional goals, and a shared philosophy concerning the kinds of technology-supported activities that would support those goals. Site-based management and grant opportunities can serve as catalysts for such discussions.
- ***Adequate technology access is needed for all students.*** To the extent that there are only a few computers in regular classrooms or computers are clustered in a few labs in one part of the school, most teachers have little opportunity to, and indeed feel little responsibility for, integrating technology into their instruction. We conclude that a classroom needs roughly one computer for every four students if students are to have the kind of access they need to engage in significant technology-supported projects.
- ***Teachers need time to learn to use technology and to incorporate it into their own curricular goals.*** Particularly after the initial hurdles, learning to use a new piece of hardware or software in a mechanical sense is a fairly short-term activity. Thinking about how technology can support one's own instructional goals, however, and learning how to orchestrate a class in which students are doing challenging projects, portions of which are technology based, take much longer. It is this latter kind of training that is all too often missing from technology implementation efforts. These kinds of learning need to occur over time, preferably with opportunities to observe models, to practice, and to receive feedback on one's actions.
- ***Easily accessible technical support is critical.*** Most teachers have limited technology experience, and, even if they are comfortable with using a technology they have not completely mastered in front of their students, these teachers will not be willing to plan around technology use if there is a good chance they will encounter technical problems that they cannot get fixed for days or weeks. Many more teachers will incorporate technology into their teaching if on-site technical assistance is readily available.
- ***The system should provide rewards and recognition for exemplary technology-supported activities.*** Like the rest of us, teachers are influenced by the reward structure around them when it comes to deciding where to place their energies. Not surprisingly, school leadership that values technology and education reform activities is associated with more widespread and sustained emphasis in these areas.
- ***Good curricular content must come first.*** Although in some cases the availability of new technology may inspire projects, it is critical that strong curriculum content drive the design of technology-supported activities. For some, there will be a temptation to assign projects that use an exciting new technology but have little curricular value. Starting

planning with educational needs and instructional goals can provide the discipline to keep technology-supported projects “on track.”

- ***The project should provide opportunities for teachers to collaborate with peers.*** The most ambitious and successful technology-supported projects typically were planned and executed by teacher teams rather than a teacher working alone. All the well-known advantages of team work, such as multiple sources of inspiration, expertise, and energy, apply to the difficult job of bringing off a student-centered classroom. When teachers work together, they seem to plan more far-reaching and ambitious activities than when they work in isolation.
- ***Technology should be used across subject matters and classrooms.*** There is a certain amount of “overhead” that goes with learning to use any new technology. Students need to acquire keyboarding skills and learn how to get into programs and files and to store their work in appropriate ways. The more classes and grades over which this “technology overhead” can be spread, the better. Moreover, when technology is used across a broad range of classes, many more students find enjoyable uses for new technology applications and feel confident about their ability to learn them.

Costs for implementing technology-supported reforms will vary from school to school, depending on the kinds of technology used, the number of students, and the requirements for major infrastructure investments (e.g., wiring and structural modifications). As an order-of-magnitude approximation, we estimate that if costs for the needed additional teacher training and preparation time are included in the projection, attaining the vision of technology-supported constructivist classrooms will run about $400 to $500 per pupil a year. Teacher training and preparation costs are the missing or underfunded elements in many technology implementation budgets.

Policy Implications

We believe that the difficulty we experienced in finding schools with large numbers of classrooms incorporating technology-supported constructivist teaching and learning approaches is in itself a significant finding. The scarcity of these classrooms testifies to the magnitude of the change we are looking for and the challenges—individual, organizational, and logistical—to making it happen.

It is clear from our case studies that the effects that technology has on students depend on the instructional context provided by individual teachers. This finding implies not only that the impact of technology will vary from classroom to classroom but also that the issues of teacher buy-in, teacher training, and teacher support are essential to success. Approaches in which a higher level of the education system decides what equipment a school will get or how they are to use it, where teachers do not participate in the process of thinking through instructional goals and selecting appropriate technologies and software to match them, are likely to lead to disappointment and wasted resources. At the same time, we do not advocate an entirely bottom-up approach. With no support, guidance, or encouragement from the system, a few exceptionally dedicated teachers will put in the time and energy to conceive and implement exciting technology-supported projects, at least for a while. Their students will benefit from their work and gain a new confidence in their ability to learn by using technology. Most students will never receive this kind of instruction, however, if there is no systemic support for it. Innovations have a fragile existence, particularly when they are not consistent with district or state curricula and accountability measures. Without institutional support, innovations often die off when their champion leaves or becomes discouraged. Higher levels of the education system have a responsibility to provide a framework that invites, supports, and sustains innovation.

These levels of the system have an important role also in guaranteeing equality of access. Student homes vary dramatically in the amount of technology available, and without state action, differences among schools serving advantaged and disadvantaged students are likely to reinforce such inequalities.

The fact that we identified classrooms and schools that do approximate our vision and that do so with students from all segments of our society is an encouraging message. Technology, project-based learning, and advanced skills are not the exclusive province of older, economically privileged, or fluent English-speaking students. Our case studies show clearly that these approaches are powerful motivators for students from all economic, linguistic, and cultural backgrounds. ***The most economically disadvantaged students in our society can use technology tools to support their own learning, to create high-quality products, and to support collaboration with others.***

In addition to the challenges to teachers, schools, and the education system described above, making technology a force for learning and positive change in our schools poses challenges to our communities. We think it is no accident that only one of our nine sites was able to launch its technology-intensive reform agenda without a significant level of funding from organizations outside the education system. In eight cases, private corporations and foundations and/or research organizations with external funding were pivotal. In an era of diminishing education budgets and public reluctance to raise taxes, ***we are unlikely to see the kinds of activities described in this report available to most of our children unless the private sector engages actively, constructively, and over the long term with schools that are eager to make technology part of significant efforts to improve.***

Overall, our research suggests that the press for reform is worthwhile, but it must be coupled with the realization that, especially when technology is involved, ***reform takes an extended period to come to fruition, requires significant resources, and must attend to teachers' needs for support in undertaking both new learning and more difficult roles.*** Technology is not an easy route to transforming schools, but our case study sites suggest that it is an exciting one.

1. INTRODUCTION

Computing power has become more available and affordable than ever before. Satellite transmission can beam instructional material to sites thousands of miles away. Computer graphics can create “virtual environments” in which the user sees and interacts with an artificial three-dimensional world. Tools to support computer applications make it possible for school children to do everything from communicating with their counterparts on the other side of the world to building their own curriculum materials in hypermedia formats to collecting and analyzing data much as practicing scientists would. Software for computer-supported collaborative work enables students and researchers thousands of miles apart to view and manipulate the same data sets simultaneously.

Having witnessed technology’s transformation of the workplace, the home, and, indeed, most of our communications and commercial activities, many are looking for comparable changes within schools. During this era of widespread education reform activity, it is not surprising that educators, policy-makers, and business and other community groups are looking to technology as a tool for reshaping and improving education.

As a counterpoint, there are those who argue that multimedia and the information superhighway are simply the latest in a long line of innovations that have been touted naively as the instrument for transforming schools. What happens instead, these critics assert, is that the technology is either adapted to traditional school structures and teaching styles, if it is sufficiently flexible, or discarded if it cannot be so adapted (Cohen, 1988; Cuban, 1986). Piele (1989) points out that although microcomputers have found their way into schools in large numbers, they have failed to transform schools because they are typically set off in a computer “lab,” usually supervised by someone other than the classroom teacher. Thus, most teachers can and do “ignore them altogether” (p. 95). Cohen concludes that uses of instructional technology that break the mold of conventional instruction are most likely to be adopted “at the margins,” that is, in advanced placement courses, special education, or vocational training. The central instructional program remains much as it was 50 years ago, untouched by the technological revolution going on around it.

Fortunately, this pessimistic picture does not apply universally, and there are schools that have been using technology on a broad scale for 5 years or more within the context of a serious reform effort. We have the opportunity to profit from their experiences in trying to understand the factors that make technology-supported innovations more or less successful from an education reform perspective.

Study Aims

This report summarizes findings from a 4-year study of technology's role in promoting education reform. The study had two complementary purposes:

- ***To promote an understanding of how technology can support constructivist teaching at the classroom level.*** Such an understanding requires both a framework relating technology use to desired student learning outcomes and multiple, fully described concrete examples of good instructional uses of technology.
- ***To describe and analyze technology implementation factors.*** What promotes or inhibits effective implementations of technology? What can parents, teachers, administrators, the business community, and policy-makers do to promote and sustain technology-supported education reforms?

Our first goal reflects a theoretical model of constructivist classrooms structured around project-based learning and authentic tasks, as described in more detail below. In these days of rapid technological advances and media hype, it is all too easy to assume that there is some educational value that adheres to a new technology per se. Yet, the research literature shows us that the instructional value lies in the way the technology is used and in the activity structure that surrounds it, rather than in the hardware or software itself (Means et al., 1993). We studied technology-using classrooms in order to provide illustrations of content-rich, technology-supported constructivist learning activities that could inspire teachers, not to try to duplicate the described activities, but to create something comparable fitting their own circumstances and local curriculum goals.

Our study's second purpose was to provide school administrators, teachers, parents, community leaders, and education policymakers with information about implementing technology-supported reforms that would help them profit from the experiences of pioneering technology-using schools. The school as a whole, rather than the individual classroom, was our basic unit of study for this purpose. By interviewing administrators, technology coordinators, students, and teachers, we sought to understand the histories of both education reform efforts and the technology implementation at the school level, as well as the ways in which the two efforts (technology and reform) were or were not intertwined.

Thus, the data collection and analysis occurred along two tracks, the classroom level and the school level, but always with the goal of understanding how the school's approach to implementation set the stage for the observed classroom activities.

The data collection portion of this project consisted of case studies of nine schools or projects using technology as part of their education reform efforts. The nine sites were selected from a set of nearly 40 schools nominated as worthy examples of educational uses of technology. They were chosen with an eye to representing the diversity of American schools and students and the very different paths to implementation that technology-supported innovations may take. At the same time, we sought sites that used technology not for its own sake, but rather as a support for constructivist learning activities. Within each school, we interviewed and observed a range of teachers, selecting several who conducted interesting, technology-supported activities for more concentrated study. (More details about methods and selection criteria are provided in Chapter 3 of this report and in the Technical Appendix.)

Conceptual Framework: Educational Reform Through Project-Based Learning

Advances in cognitive psychology have sharpened our understanding of the nature of skilled intellectual performance and provide a basis for designing environments conducive to learning. There is now widespread agreement among educators and psychologists (Collins, Brown, and Newman, 1989; Resnick, 1987) that the advanced skills of comprehension, composition, reasoning, and experimentation are developed not by the passive reception of facts but by the active processing of information. This *constructivist* view of learning, with its call for teaching basic skills within authentic contexts (hence more complex problems), for modeling expert thought processes, and for providing for collaboration and external supports to permit students to achieve intellectual accomplishments they could not do on their own, provides the conceptual underpinnings for our investigation of technology's role in education reform.

Although variously described, the student-level outcome goals of most reform efforts are to increase learning, especially of advanced or higher-level skills, and to enhance student motivation and self-concept. In our view, the catalyst for this transformation is centering instruction around *authentic, challenging tasks*. Research suggests that schools have decomposed and decontextualized tasks into discrete component skills (e.g., learning algorithms for finding square roots) that have no obvious connection with anything students do outside of school. Reformers argue that, instead, students should be given tasks that are personally meaningful and challenging to them (e.g., describe their city to students in another part of the world). As shown in Figure 1, the provision of authentic challenging tasks has implications for almost every other part of pedagogy, leading to the kinds of changes reformers advocate. Authentic tasks are almost always more *complex* than the tasks assigned with a discrete-skills approach, and they also will tend to be *multidisciplinary* (e.g., describing the city means assembling geographic and historical facts as well as working on composition skills), a feature that conflicts with the standard middle and secondary school structure of distinct disciplines. Further, the fact that the tasks will be more complex suggests that *longer blocks of time* will be required to work on them, again conflicting with the notion of 50-minute periods for distinct subject areas.

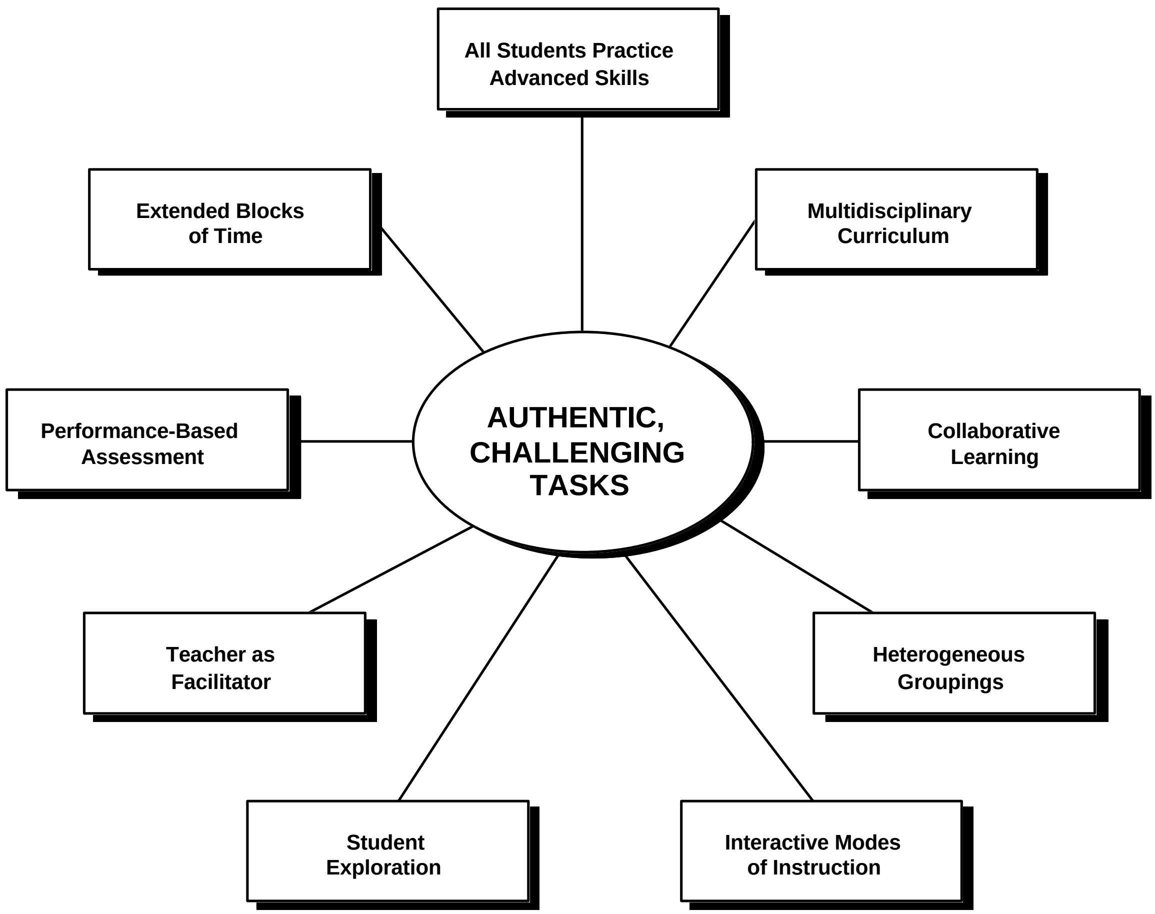

FIGURE 1. AUTHENTIC CHALLENGING TASKS AS THE CORE OF EDUCATION REFORM

Complex tasks permit students to take a more active role in defining their own learning goals and regulating their own learning. Students *explore* ideas and bodies of knowledge, not in order to recite verbal formalisms on demand but to understand phenomena more deeply and search for information they need for their project work. Instruction becomes *interactive*. Complex, authentic tasks lend themselves to *collaborative work*. Among the advantages of collaborative learning for students are opportunities to negotiate the purpose of their work, the meaning of the terms they use, and so on. As students justify their conclusions and act as external critics for each other, they become more reflective about their own thinking and able to evaluate the quality of their own work.

Collaborative projects facilitate the adjustment of tasks to accommodate individual differences. Thus, it becomes feasible to teach *heterogeneous groups* of students who vary in age, expertise (e.g., each group may need a video expert), achievement levels, and so on. Within such groups, the experience of explaining something to a fellow student who does not understand it can in itself be an educationally valuable experience.

In the constructive learning model, the *teacher becomes a facilitator and "coach"* rather than knowledge dispenser or project director. Teachers are responsible for setting up inquiry projects, arranging for access to appropriate resources, and creating the organizational structure within which groups do their work, but once work begins, teachers no longer have the total control of the direction of instruction that they exercise in more conventional classrooms. Rather, they allow students to follow diverse learning pathways.

This is not to say that all school activities need be, or should be, project based. We need not throw every piece of skills practice out with the bath water as we seek to make schools more stimulated, student-centered places for learning. Moreover, computers have proven benefits in providing extensive, individualized practice on basic skills (Kulik and Bangert-Drowns, 1984; Samson, Niemiec, Weinstein, and Walberg, 1986). Rather, we emphasize project-based learning because it is such an essential part of the thinking behind education reform. In this study, we have sought to explore and document the role that technology can play in supporting project-based learning and the evolution of classrooms in directions consistent with the reform agenda.

Study Questions: How Technology and Reform Fit Together

The broad research questions addressed by this study were:

- Does technology facilitate a transition to more emphasis on constructivist, project-based learning?

- What supports are required to make technology an effective tool for constructivist approaches in a critical mass of classrooms within a school?
- What are the impacts on students and teachers when technology is introduced along with constructivist learning activities?

In Chapter 2 we summarize some of the prior research suggesting that technology can support constructivist learning activities. (See Means et al., 1993 for a more complete review.) After presenting an overview of our study approach (Chapter 3) and brief profiles of our nine sites (Chapter 4), we discuss the challenges schools face in implementing technology and the resources required in Chapters 5 and 6. In Chapter 7 we provide an analysis of our case study sites with respect to the sources of leadership for technology and education reform initiatives and the roles of various levels of the education system. We return to the question of how technology can support constructivist, project-based learning in Chapter 8, using findings from our case studies. The question of the impacts on students and teachers when technology is introduced as part of constructivist learning activities is dealt with in Chapters 9 and 10. Chapter 11 concludes the report with a discussion of implications for policy and practice.

2. REVIEW OF LITERATURE[1]

In this chapter, we provide a selective review of the literature on how technology can promote student learning. Since an exhaustive review is not possible, we attempt to illustrate the range of applications, along with a description of selected programs that represent key features. We continue with a description of ways in which technology can support student learning and the teacher activities needed to promote this kind of instruction. The final section discusses research on the effects of technology on student learning outcomes.

Technologies for Learning

Educational technologies are not single technologies but complex combinations of hardware and software. These technologies may employ some combination of audio channels, computer code, data, graphics, video, and text. Although technology applications are frequently characterized in terms of their most obvious or innovative feature (e.g., a high-speed data line or videoconferencing), from the standpoint of education, it is the nature of the instruction delivered that is important rather than the equipment delivering it. To organize our thinking for this study, we developed a scheme for classifying technologies according to the way they are used. Our categories are designed to highlight differences in the instructional purposes of various technology applications, but we recognize that purposes are not always distinct, and a particular application may in fact be used in several of these ways.

Tutorial uses are those in which the technology does the teaching, typically in a lecture-like or workbook-like format in which the system controls what material will be presented to the student. In our classification scheme, tutorial uses include (1) expository learning, in which the system provides information; (2) demonstration, in which the system displays a phenomenon; and (3) practice, in which the system requires the student to solve problems, answer questions, or engage in some other procedure.

Technologies for tutorial learning typically use a transmission rather than constructivist model of instruction. For this reason, although they have found their place in education and have the greatest rate of adoption of all types of technology within schools thus far, they are unlikely to serve as a catalyst for restructuring education. The focus of drill-and-practice computer-assisted instruction (CAI) on basic skills allows little room for the presentation of complex tasks,

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1. This chapter was prepared by Edys Quellmalz based on the report *Using Technology to Support Education Reform* by Barbara Means, John Blando, Kerry Olson, Teresa Middleton, Catherine Cobb Morocco, Arlene R. Remz, and Judith Zorfass.

multistep problems, or collaborative learning. Intelligent computer-assisted instruction (ICAI), on the other hand, has the potential to deal with complex domains, to provide models of higher-order thinking, and to probe students' understanding, but it has seldom been well integrated into a school's mainstream curriculum. One-way video technologies (such as *Ghostwriter* or *Square One*) can be very motivating but are nearly always viewed as enrichment and have not instigated fundamental changes within schools.

Exploratory uses of technology are those in which the student is free to roam around the information displayed or presented in the medium. Many of these applications have incorporated the imaginative use of video. Exploratory applications may promote discovery or guided discovery approaches to helping students learn information, knowledge, facts, concepts, or procedures. In contrast to tutorial uses, in which the technology acts on the student, in exploratory uses the student controls the learning.

Exploratory applications can support the kind of student learning that is the goal of education reform. Video episodes and information resources can present complex, authentic tasks, engage students in active problem solving, require utilization and synthesis of knowledge from a variety of domains, and provide a context for collaborative learning activities. There are, however, significant practical limitations to many of these applications. First, from the teacher's standpoint, these exciting and imaginative applications are fine for enrichment but typically don't match the core curriculum. Hence, they may find a place in the "margins" of education but don't really transform the core. Also, exploratory applications with set episodes have a relatively short "shelf life." Once students learn how to solve, complete, or engage in the complex tasks required by the simulation or video, they are ready to move on to something else. Finally, there is the issue of scarcity: complex simulations and exploratory videos are expensive to develop, hence there are few. The problem is made worse by the fragmentation of the American education market, with its decentralized buying decisions and wide variation in curricula. Technology application developers have little hope of being able to match the curriculum of enough schools well enough to have a broad market base (Levin and Meister, 1985). Without such a broad base, they see little hope of recapturing a major investment. A factor that appears likely to change the economics of producing multimedia educational materials is the potential for a much larger home-use market. Many software publishers are starting to invest in products that can be marketed for both home and school use.

Tool uses, such as the use of word processors and spreadsheets, help students in the educational process by providing them with general-purpose applications to facilitate writing tasks, analysis of data, the location of information resources, and other uses. In addition to word processors and spreadsheets, applications include database management programs, graphing software, desktop publishing systems, Internet browsers, and video recording, digitizing, and editing equipment. When technology is used as a tool, the curriculum content resides not in the software but in the instructional activity within which the tool is used. The technology itself does not convey the content (except in the limited cases where the instructional goal is to learn to use the technology tool).

Used well, technology applications can support students' work on authentic, complex tasks. The tasks in which students apply these tools—library research, scanning media, talking to experts, recording information, writing or otherwise producing compositions—reflect the kinds of work in which they will continue to engage throughout their careers. The tasks are authentic and multidisciplinary. Additionally, students who use technology tools are active learners: choosing composition topics, doing fieldwork, and, at times, teaching the teachers. Students work collaboratively, not only with each other but with researchers and teachers. The potential disadvantage lies in the fact that little or no content knowledge is embedded in a word processing program, hypermedia tool, or Internet browser. The value of activities involving these technology tools lies in the instructional context supplied by the teacher, not the technology per se. Teachers and students need to avoid the temptation to spend large amounts of time on aspects of technology use that do not further learning goals.

Communication uses are those that allow students and teachers to send and receive messages and information to one another through networks or other technologies. Interactive distance learning via satellite, computer and modem, cable links, or other technologies is one example of communication uses.

Distance learning can give students and teachers access to a broad range of resources and support collaborative projects involving complex themes. Collection and sharing of scientific data, interactions with practicing scientists, and sending work to other classrooms or publishing student products over the Internet are examples of uses of technology for communication. Widely touted for the capability to bring a broader range of resources into the classroom, communications technology also provides a sense of authenticity and importance for tasks (e.g., writing, data analysis) that are often viewed as mundane when undertaken with the classroom teacher as the sole judge and audience.

Support for Student Learning Activities

Technology can support the education reform goal of promoting student learning through collaborative involvement in authentic, challenging, multidisciplinary tasks by providing realistic, complex environments for student inquiry, furnishing information and tools to support investigation, and linking classrooms for joint investigations.

Realistic, Complex Environments for Inquiry

Teachers can draw on technology applications to simulate real-world environments and create actual environments for experimentation, so that students can carry out authentic tasks as real workers would, explore new terrains, meet people of different cultures, and use a variety of tools to gather information and solve problems. Working on "authentic tasks," which Brown, Collins, and Duguid (1989) define simply as the ordinary practices of the culture, engages students in sustained exploration and provides multiple opportunities to reflect on the decisions made in trying to address the problem. With simulations, students can get involved with a problem, often through visual media, which provide integrated contexts and help students comprehend new ideas more easily (Hasselbring, Goin, Zhou, Alcantara, and Musil, 1992).

Simulations are student centered since students make decisions and see the results of their actions. The teacher is present, but in the role of coach, using discussion to prompt students to explore different aspects of the problem space, answering students' questions, and encouraging students to elaborate their thinking and listen to other points of view. Because the problem space is always accessible (unlike real-life situations), students can revisit and revise their conceptual understanding. The examples below illustrate how technology can supply a motivating context for learning activities and support student involvement in authentic tasks.

Voyage of the Mimi—*The Voyage of the Mimi I*, developed by Bank Street College in 1985, is a 13-part television drama that portrays the adventures of a group of young scientists who are studying whales off the coast of New England. The crew conducts scientific experiments and solves technical problems. A separate documentary portrays scientists engaged in their work. Four computer modules engage students in using navigation concepts and instruments, for example, to free a trapped whale. The modules also include a microworld ecosystem, a tool for measuring and graphing physical events, and a programming environment. A book version of the TV show, classroom activities, and additional resources are available for teachers. *The Second Voyage of the Mimi* focuses on archaeology and the culture of the ancient Maya in Mexico's Yucatan peninsula in a multimedia package including 12 television episodes and two software programs—*Maya Math* and *Sun Lab*. More recently, this approach was extended in Bank Street's *Palenque* project, a digital video interactive (DVI) prototype that provides for electronic as well as thematic integration of student explorations into various aspects of Mayan culture (Wilson and Tally, 1991).

Immigrant 1850—Developed by Project Zero at Harvard University, *Immigrant 1850* provides students with access to a core set of computer-based activities in which they can adopt an Irish immigrant family and "live through" the complex decisions the family may have made in finding housing and a job, calculating finances, and shopping within their earnings. Students can use a database, spreadsheet, and word processor to calculate expenses and keep diaries (Morrison and Walters, 1989; Walters and Gardner, 1990; Walters and Gardner, 1991). Many teachers involved with the *Immigrant 1850* unit used the existing materials as a starting point to create additional innovative learning environments for their particular students, drawing on additional technology applications (e.g., an extensive on-line, visual database) and corollary activities (e.g., tracking the population of American cities, Indian tribes in Texas, etc.). Researchers also found that some teachers used *Immigrant 1850* as a model to create their own engaging computer-based curriculum units (Walters and Gardner, 1991).

Adventures of Jasper Woodbury—This series of video adventures, designed by the Cognition and Technology Group (1991) at Vanderbilt University, requires mathematical reasoning to solve complex problems in trip planning, probability and statistics, and geometry. Videos 17 to 20 minutes long provide natural contexts for learning mathematics, as well as geography, history, and science. Each video ends with a challenge, rather than a resolution. The information to solve the problem is embedded within the video, which can be reviewed and studied to pick out relevant information.

The Cognition and Technology Group asserts that by being video based, the learning experience is more motivating and allows for more complex problems than could be presented in a written or audio-only medium. Motivation and comprehension are further heightened through use of a story providing a realistic context and a familiar structure for the problems presented. The narrative format provides for the introduction of other subject matter topics; for example, the skill of map reading is used in an episode dealing with trip planning, thus providing links to geography and navigation. The learning format is generative; the stories in the *Jasper* series must be completed with a resolution provided by the students. Generating this resolution requires solving a complex mathematics problem. Data needed to solve the problem are embedded in the story itself, just as in other good mystery stories. The videos are created in pairs of related adventures so that students can transfer mathematical or reasoning concepts learned in one video context to new contexts.

The *Jasper* videos are available in a variety of media: videotape, videodisc, and hypermedia (Cognition and Technology Group, 1991). In the hypermedia version, students can engage in basic skills practice, change parameters of the original problem to generate an analogous problem (e.g., new locations, goals, etc.), and explore related mini-adventures.

Project GALAXY—The GALAXY Foundation has developed a set of curriculum materials and instructional strategies integrating television broadcasts, classroom hands-on activities, and communication with the project office and among participating classrooms via telefacsimile. Curriculum materials have been developed in both science (for grades 3-5 and K-2) and language arts (for grades 3-5). In both cases, the curriculum is structured around a series of television episodes in which a multiethnic group of preteens tackle, encounter, and reason about puzzling situations. Students are encouraged to fax their own suggested answers or approaches for the problems in to GALAXY Central. Some of the telefacsimiles are incorporated into later televised episodes. The television broadcasts are supplemented with teacher training, a teacher's guide, a student magazine, and a faxed response bulletin board that lists the names of students who sent faxes. In addition to these resources, the materials for science include hands-on science activities developed by the Lawrence Hall of Science (FOSS and GEMS) and take-home science kits.

Antarctica Project—As part of the Middle School Mathematics through Applications Project of the Institute for Research on Learning, students participate in a multidisciplinary project to design an Antarctic research station. Using architectural design software developed especially for the project, students practice mathematics skills as they deal with issues such as heat loss, building dimensions, and building costs. Students work in teams to develop their designs and then present their work to the entire class for review and critique. Teacher materials support linkages between the design activities and topics in the mathematics curriculum.

Information and Tools to Support Investigation

Computers, with their calculation, database, and graphic capabilities, support the work of practicing scientists and mathematicians. Technology specifically designed to support student learning in these areas is starting to gain acceptance in schools.

Model-It—As part of the ScienceWare project at the University of Michigan, Eliot Soloway and his colleagues have developed and field tested software that allows students to construct scientific models and simulations without having to master a programming language or advanced mathematics. Called Model-It, this software has been used thus far in a year-long ninth-grade thematic curriculum on the ecology of a stream. A digitized photo of the area being investigated (i.e., a local stream) provides a motivating, customized context. Students then hypothesize about the relationships among variables (such as the phosphate level and the amount of algae) and use the system to clarify and test their models. The system offers options of specifying the nature of the relationship between two variables (i.e., changes in slope) in simple language (“as stream phosphates increase, stream quality decreases by less and less”) with the option to see what the graph of this relationship looks like. Real data can be entered into a table and then viewed as a graph for comparison with the graphs based on hypothesized relationships. Students can run their models and view meters showing the value of each variable and how it changes over time (Soloway, 1995).

Geometric Supposer—*Geometric Supposer* is a set of microcomputer software tools developed by Judah Schwartz and Michal Yerushalmy to teach high school geometry through a guided-inquiry approach. The Supposers, which are supplied on three floppy disks, allow the user to make geometric constructions of the sort created with a compass and straightedge (Wiske and Houde, 1988). Students engage in inductive thinking and have a chance to “reinvent” definitions and theorems and to explore new, interesting, and complex geometric ideas.

Collaborative Visualization Project (CoVis)—By fundamentally relying on information networks and remote multimedia services, distributed multimedia learning environments extend the limits of individual classrooms. CoVis is a testbed consisting of an advanced network that integrates telecommunications, multimedia, computing, and new collaboration software for investigation of the potential of collaboration and scientific visualization technologies. Two high schools, scientists, science museums, and a host of experts are developing project-enhanced science learning. Shared workspaces and two-way audio/video connections allow for collaborative visualization of science phenomena, data, and models. The project is crafting software applications—a Collaborative Science Workbench and a Science Learning Resource Directory—to sustain collaborative visualization activities across remote classrooms and other sites (Pea, 1993).

Video for Exploring the World (VIEW)—VIEW supports the use of video as a type of laboratory instrument. VIEW provides students with quick access to real-world data such as human and animal motion as well as the behavior of crowds, flocks, and traffic. Students analyze real phenomena rather than abstract models. Frame-by-frame viewing and time-lapse allow student to shrink and expand time to work with otherwise inaccessible phenomena. With the capability for digitizing video so that it can be shown on the screen, manipulated, and placed on the Internet, video is used as a powerful and exciting visualization tool for scientific investigations (Rubin, 1993).

Classroom Links for Joint Investigation

Computer networks enable students and teachers to move the learning process beyond the boundaries of the classroom and into the world outside school (Newman, 1992). By bringing telecommunications applications into their classrooms, teachers create environments where students can communicate via electronic mail with other students, participate in collaborative projects, and gather and pool information in a joint endeavor to understand issues.

Computer-Supported Intentional Learning Environments (CSILE)—CSILE was developed by Marlene Scardamalia and Carl Bereiter at the Ontario Institute for Studies in Education. It has been used in a research program within Toronto schools for over 5 years. CSILE functions as a "collaborative learning environment" and a communal database, with both text and graphics capabilities. This networked multimedia environment allows students to generate "nodes," each containing an idea, graphic, or piece of information relevant to the topic under study. Types of nodes students can enter include "problem," "my theory," and "new information." Nodes are available for other students to comment on, leading to dialogues and an accumulation of knowledge. Students have to label their nodes to be able to store and retrieve them; over time, they come to appreciate the value of a precise, descriptive label. In addition to receiving writing practice as they create their own nodes, students get practice reading the nodes generated by others.

In this project, researchers Scardamalia and Bereiter seek to develop a supportive discourse community by using the CSILE communal database as well as guidelines for students to formulate and test theories. CSILE is being used in nine sites, including elementary, secondary, and postgraduate levels. Findings indicate that CSILE students show significant advantages over control students on standardized tests, portfolio entries, depth of explanations, and beliefs about learning (Scardamalia and Bereiter, 1993). Previous CSILE applications have used local area networks within schools; implementations of CSILE communities across schools are planned.

Learning Circles—The AT&T Learning Network links classes from geographically diverse locations into "learning circles" to accomplish shared educational goals (Riel, 1991). Each classroom within a learning circle has the opportunity to design projects and request information from the other circle partners for projects such as how weather and seasonal patterns affect the daily lives of people in different locations, the influence of mass media on children's lives, and a survey of cities in transition (Riel, 1990a; 1990b). Students in New York, Australia, and Canada, as well as other distant locations, researched and then traded stories about the history of their own communities. After collecting the information from their distant partners via the telecommunications network, the students worked with the information they received—analyzing, evaluating, synthesizing, and eventually publishing the project in a cooperative learning circle publication.

Research suggests that students are better able to function as intellectual critics for distant peers than for themselves or classmates and that they learn to write better when physical distance makes clear the need to provide explicit content for the reader (Riel, 1992). An additional advantage is that physical and sensory limitations become “invisible” in this medium. Hearing-impaired students in one learning circle class wrote to another class about what it is like to be deaf and how they are often treated as stupid (Riel, 1992). Riel also (1990b) found that the teacher became a learner alongside students, serving as a model of active learning.

TERC Network Science Programs—Over the past decade, TERC has been linking groups of classrooms to each other and to professional scientists who can help students explore pressing global questions. TERC’s network science programs are based on the premise that students can carry out scientific investigations with real scientists and that computers can enhance this enterprise (Julyan, 1991). Students conduct experiments, analyze data, and share results with their colleagues by using a simple computer-based telecommunications network (Julyan, 1991).

Kids Network. One of the TERC network projects, the National Geographic Kids Network, involves students and teachers across the United States and in a number of foreign countries working collaboratively on science projects such as a study of acid rain (TERC, 1990). Students collect data on the pH of their local water, share the data with the other schools on the telecommunications network, and consult with scientists (Lenk, 1988). Themes of additional curriculum units are “Too Much Trash,” “What’s in Our Water?,” “Weather in Action,” “What Are We Eating?” and “Solar Energy.”

TERC Star Schools. Another TERC network project, the Star Schools project, involves secondary students and teachers from across the country and recognized resource centers. These groups tackle compelling problems such as measuring radon levels in their schools, designing solar houses, collecting weather data, and exploring “mathematical chaos” (Berger, 1989). Teachers feel that this environment allows students to realize that important problems are complex and may have more than one solution.

Earth Lab—Directed by Denis Newman of Bolt, Beranek and Newman, Inc., this project created classroom environments in which students used collaborative workspaces to learn elementary earth science in much the same way as scientists do (Newman, 1992). All of the computers in the school were connected via a local area network (LAN) to a hard-disk drive, which allowed for central storage of data, text, and programs. Teachers created environments for teaching and learning that were decompartmentalized (Newman, 1990). The computer lab was increasingly used in a "heterogeneous manner," with groups of students from several classes working on different projects simultaneously. The communication technology designed to bring the school in closer contact with other parts of the globe, also appeared to reduce the barriers between classes within the school (Newman, 1990; 1992).

Global Learning and Observations to Benefit the Environment (GLOBE)—Beginning in 1995, GLOBE will link students throughout the world in over 2,000 schools to each other and to a worldwide community of earth scientists. The program's goals are to promote students' awareness of environmental issues and the earth as a dynamic system. The design and implementation of GLOBE is informed by earlier projects in which networked classrooms around the United States and around the world have worked collaboratively to collect scientific data, aggregate it, analyze it, and discuss its interpretation. The project will test the effectiveness of networked technology for supporting science education on an international scale.

Supports for Teachers

Technology supports teacher functions that are fundamental if teachers are to provide authentic, active learning experiences as envisioned by education reform goals. These functions include developing and tailoring instructional materials, conducting ongoing assessment of student learning, expanding teachers' content and instructional knowledge, and communicating with parents. In addition to being necessary for providing challenging, constructive learning experiences, these functions constitute important aspects of the professionalization of teachers, another goal of education reform.

Tools for Developing and Tailoring Instructional Materials

In inquiry-based environments, students pursue different questions, work at different speeds, use a variety of materials, engage in different activities, and work in flexible groupings. Teachers are increasingly able to draw on technology resources to develop and tailor instructional materials to better meet individual student needs. Access to information, curricula, and experts over the Internet offers teachers new supports for curriculum development. General-purpose software, such as *HyperCard*, or the various presentation and multimedia packages give teachers tools for creating their own curriculum materials. Given support and time, many teachers would enjoy the challenge of developing their own materials, but these conditions are often lacking, and not all teachers would welcome the activity even given the support. An alternative way of involving teachers in developing technology-based instructional materials is to be able to adapt instructional materials to meet the needs of their particular students. Few teachers have programming skills, however, so the provision of tools to make it easy to extend and modify instructional software is very desirable. This kind of capability rarely has been built into commercial materials in the past but should be pressed for in the future.

Supports for Ongoing Assessment

Technology can support the assessment of student work in ways that are useful for guiding instruction. Specifically, technology facilitates (1) obtaining a trace of student thinking processes; (2) providing contexts for authentic assessment; (3) storing and retrieving student work and associated comments; and (4) setting individual goals and managing instruction.

Create Traces of Student Thinking Processes—Collins, Hawkins, and Frederiksen (1991) assert that appropriate technologies have a strong role to play in tracking the process of learning and thinking by (1) recording how students learn with feedback in novel situations; (2) recording students' thinking and strategic processes by tracing the process with which students maneuver through a problem or task; and (3) recording students' abilities to deal with realistic situations.

Earlier technology (*The Voyage of the Mimi* is an example) did not have built-in ways to monitor or track students' progress, making it difficult for teachers to follow the actual learning process, especially for students with learning difficulties (Hawkins and Sheingold, 1985; Morocco and Dalton, 1990). To assess student learning of navigation skills for the *Mimi* cases, Education Development Corporation designed a hands-on "performance assessment"—placing students individually at the computer with a researcher who took on the role of clinical interviewer as the student played the navigation game individually (it is usually played collaboratively with other students). This approach is one model for teacher assessment of individual student learning in a computer-based environment.

An alternative approach is made possible by recent software environments that have the capability to gather a "dribble file" of all of the student's activity in the environment. This file can be placed in a student's portfolio along with the student's visual and writing products. The teacher can examine the file to discern the blind alleys, alternative designs, and way of proceeding that characterized the student's efforts.

Moreover, the increased visibility of work on a computer screen increases the likelihood that teachers will engage in informal, ongoing assessment as students are working (Morocco, Dalton, and Tivnan, 1989; 1992). Hawkins and Sheingold (1985) found that teachers noticed more about the way their students were learning as they circulated among students working at computers.

Video technologies provide another means for recording and tracking student learning processes. For example, teachers at Skyline Elementary, a Model Technology School in California, have used video equipment (a MicroMacro Lab with table-mounted cameras attached to widescreen video) as a tool for observing and analyzing the strategies used by young children engaged in mathematical problem solving with manipulatives.

Provide Contexts for Authentic Assessment—Technology can be used to present authentic tasks in a standardized manner, thus providing a context for assessing advanced skills. Each video episode in SRI's *Becoming Successful Problem Solvers* series, for example, presents two child actors engaged in an extended effort to solve an interesting, real-life mathematical problem. Accompanying the episodes are paper-and-pencil instruments and open-ended questions to help teachers get at students' beliefs about problems (e.g., Can there be more than one right answer?).

Store and Retrieve Student Work and Associated Comments—The issue of assessing and meeting individual student needs in a simulated environment, where students are constructing knowledge over time through a variety of experiences, was a critical one in the immigration project described earlier (Walters and Gardner, 1991). In a revised version of *Immigrant 1850*, researchers included an extensive chapter on how to assess student writing by providing guidelines for assessment along with samples of student work to exemplify those guidelines, including drafts and plans, as well as final products, commentary, and reflection.

Set Goals and Manage Instruction—Teaching involves a great deal of management of student instructional goals and performance records, especially when instruction is individualized. One of the biggest draws for integrated learning systems (ILS) has been their inclusion of software to automate this process. Although the discrete-skills approach embedded in most such systems is not easily incorporated within an interdisciplinary project-based approach, technology can support more adaptive strategies for managing and documenting student learning. At the Saturn School in St. Paul, teachers collaborated with software developers to design technology to respond to, store, and manipulate complex student performance data. The system was designed to keep track of individual student Personal Growth Plans, consisting of goals negotiated with staff and parents but written in the student's own words (Bennett and King, 1991). This plan can be stored on both teacher- and student-accessible networks, where students and teachers can set goals and track student accomplishments. The student or teacher can query the system for learning activities (e.g., courses, workshops, community volunteer opportunities, mentorship programs) relevant to a particular goal. There are pop-up windows for teacher comments and notes regarding the student's activities and goals. The student's portfolio may include both hard copy and items that are stored electronically on the network, including text files, *HyperCard* stacks, and videos.

Opportunities to Share and Expand Teacher Knowledge

Telecommunication systems are helping teachers break out of their traditional isolation to connect with colleagues and professionals in distant locations. These interactions can help teachers develop a clearer image of effective teaching and learning environments, understand how technology enables them to create these environments, learn about effective instructional strategies, share information about students, and gain emotional support for change.

Interaction with Colleagues—The opportunity for teachers to work cooperatively with other teachers is considered a crucial program ingredient in the AT&T Learning Network described previously. Beyond providing an avenue for communication about cooperative projects, the AT&T Learning Network provides a forum for more in-depth and reflective communication between professionals. Riel (1990b) found that teachers who were part of the AT&T learning circles asked each other for suggestions and advice and thus gained new ideas about classroom organization and teaching practices. Indeed, when the teachers participating in the AT&T Learning Network were asked about the benefits of educational electronic networking, most rated *their own learning*, not the learning of their students, as the most important benefit of the program (Riel, 1990b).

The Teaching Teleapprenticeship program explores several models for improving the preparation of teachers (Levin, Waugh, Brown, and Clift, 1993). Teacher education students receive hands-on opportunities to explore collaborative learning models through direct participation in a wide variety of electronic network-based learning experiences. One type of teleapprenticeship involves teacher education students in many diverse, instructional contexts; another apprentices candidates with practicing teachers. Yet another type involves candidates in mentoring activities with K-12 apprentices from participating classrooms.

Access to Subject Matter Experts and Resources—In addition to providing links to colleagues, technology can give teachers access to experts and learning resources in the subject matter they are trying to teach. Even the best-prepared teacher cannot know everything in a given field, and knowledge about new developments is by definition vested in just a few individuals. The Urban Math Collaborative (UMC) links teachers and university mathematicians. Discussions on the electronic network of the UMC have deepened teachers' content knowledge and have also touched on teaching issues that do not get dealt with as openly and meaningfully in other forums (Driscoll and Kelemanik, 1991).

In addition, a number of network-based projects are being developed to support teachers' professional development. The National Teacher Enhancement Network (NTEN) delivers on-line graduate credit courses through the University of Michigan for high school science teachers nationally and internationally. In California, the Telemation Project trains telementors, who in turn train other teachers in the use of network technology for communication, resource access, and curriculum development. Teachers learn to use Internet browsers such as *Netscape* and *Mosaic* to search for resources on the World Wide Web. Other projects, such as the Tennessee Valley Project and California On-Line Resources in Education (CORE), connect teachers to Internet resources.

Supports for Communication with Parents

Voice Link services, provided to over two dozen Connecticut towns by the Southern New England Telecommunications Corporation, allow teachers to inform parents about homework, report cards, and field trips (Douglas and Bransford, 1991). Voice mail to update parents on material covered in class and on homework and voice bulletin boards to post school activities can keep students, parents, and the community informed about the activities of the school (Heller, 1991). Using current telephone technologies, several communities have already established "Homework Hotline" or "Dial a Teacher" programs. Lesgold et al. (1992) envision a time when emerging wider-bandwidth networks make it possible for parents to get much more than a listing of required homework exercises.

Challenges for Teachers Using Technology

The initial enthusiasm for technology (especially computers) included rosy predictions about making teachers' jobs easier. Experience has shown these early predictions to be naive. Teachers are nearly unanimous in concluding that, in the early stages of technology implementation, at least, their job becomes harder. The technical demands posed by technology use are just the tip of the iceberg. Teachers must be able to select, adapt, or design technology-enhanced materials that meet the needs of their particular students. Technology-enhanced curricula often place new demands on teachers' subject matter knowledge and nearly always require them to take on new roles as curriculum designer, team builder, and coach. Complex, collaborative technology-based work can make assessing individual students a complex undertaking.

Teachers contemplating the above set of issues might well ask themselves whether their involvement with technology will be worth the trouble. The response from thousands of teachers who have tried it would be a resounding "yes!"

Learning How to Use a Variety of Technology Options

In addition to learning how to use a variety of technology applications themselves, teachers need to develop criteria for selecting applications and skill in weaving them into broader instructional activities, strategies for allocating time for technology access among students, and techniques for managing technology-based instruction within the classroom. All of these decisions need to be closely tied to an examination of curriculum issues and the intended learning outcomes.

Increasingly, wide area networks are providing interested groups of teachers with information about new technology applications and curriculum approaches. Although useful, access to these resources does not fill all of teachers' needs for technical support, nor does it necessarily provide them with an efficient way to assess the potential power of each technology application with respect to inquiry-based teaching and learning. Driscoll and Kelemanik (1991) have found that it is very difficult for teachers to sustain regular, substantive discussions on a network. The discontinuity in conversation can be a big disadvantage because if some questions go unanswered, a request is ignored, or interesting lines of discussion are not pursued, the conversation may falter and users may drop out. Riel (1990a) has found that the use of bulletin boards is very time-consuming and that it is sometimes inefficient for teachers to negotiate their way through them in search of applicable and appropriate ideas or conversations.

Using, Adapting, and Designing Technology-Enhanced Curricula

When teachers integrate technology applications into the curriculum, they knowingly or unknowingly are curriculum developers. Basically, there are three different models for integrating technology into student-centered curricula. In one model, teachers identify an appropriate piece of software (e.g., *SimCity*) or other technology resource and integrate it into their existing instruction. In another model, the teacher selects and sequences resources to use from a complete and comprehensive multimedia curriculum (e.g., Project GALAXY). In a third model, teachers construct a curriculum unit around a theme or topic by using a variety of technology applications, generally with an emphasis on tool and communications software (e.g., word processing, spreadsheets, sharing information over the Internet).

Any technology integration requires that teachers engage in rethinking and reshaping their curriculum. Teachers should pose questions such as: What does the technology offer my students in terms of developing concepts and content? How does it help them to carry out inquiry processes? How will they work together collaboratively or cooperatively? What is the relationship between the technology and other instructional materials? What knowledge, processes, and skills do students need before using the technology? What new knowledge of my content or discipline, of teaching, or of technology do I need in order to foster new learning in my students?

Expanding Content Knowledge

Many of the technology applications require a broader and deeper knowledge of the discipline than may be required by curricula that assume that teachers transmit a fixed body of information. After studying teachers' use of *Geometric Supposer* for one school year, Yerushalmy, Chazan, and Gordon (1988) concluded that for the teacher to be successful, he or she must know the subject matter, function as a leader and manager of a community of learners, be flexible, and have time for planning and preparation throughout the year. Similarly, Wiske (1990) concluded from her study of high school teachers who used *Geometric Supposer* that teachers need a deep and wide knowledge of their subject matter and a clear understanding of the process of building mathematical understanding to use the software effectively. Research findings on *The Voyage of the Mimi* indicate that teachers' science and mathematics background and their preferred teaching style had an impact on what, when, and how they used the materials. Interestingly, the flexibility of the materials, and the ability to make decisions about when and how to use particular materials, helped teachers grapple with their own limitations in science and mathematics (Martin, 1987).

Taking on New Roles—Although teacher-designed inquiry environments can have enormous motivating power for students, they require advanced skills—in curriculum and instruction, in team building and interdisciplinary curriculum design, as well as in technology—on the part of the teacher. When teachers use and develop inquiry-based curricula that integrate technology, their role in the classroom becomes more that of a coach or facilitator of student learning. For teachers and students to follow multiple routes to knowledge-making, a curriculum needs to be flexible. Teachers cannot—and should not expect to—have a total grasp of the content related to every topic. What they do need to know is how to help guide students through the meaning-making process. Teachers often feel vulnerable as they take the risk of shifting from a more comfortable knowledge transmission mode of teaching to inquiry-based teaching.

Responding to Individual Students—Many technology applications (e.g., word processing, databases) offer teachers a window into the student's thinking, inquiry, and problem-solving processes. When the work students are doing is visible on a monitor or printout, teachers have access to students' misconceptions, the ways in which they sort and categorize information, the relationships they form among ideas, and the conjectures they make. Teachers need good diagnostic skills to take advantage of the opportunities provided by the technology, however. Good judgment about when and how much to intervene is important, also. Intervention in students' work at an early stage can be helpful, but it also can thwart students, short-circuiting their own construction of knowledge (Newman, 1990; 1992). A challenge related to the collaborative learning approach used in many technology-supported projects is finding a balance between group and individual assessments. The essence of a collaborative project suggests an emphasis on evaluating group performance, but teachers also need to tease out enough evidence of individual performance to be able to identify any students who have become lost in the dynamics of the group.

Effects on Student Achievement

Although an argument can be made for including technology in schooling for its own sake, many policy-makers and community members want evidence of the effects of technology on student learning to support technology investments. In this section, we describe a sample of studies that represent the major approaches and issues in the research literature.

"Horse Race" Studies

When a new instructional technology appears on the scene, it is quite natural to want to compare its effectiveness with that of existing technologies. Early studies compared instruction via radio and, later, television, with learning based on classroom lectures or textbooks. More recently, hundreds of studies have been conducted comparing computer-assisted instruction with more traditional modes (Kulik, Bangert, and Williams, 1983; Samson, Niemiec, Weinstein, and Walberg, 1986). Smaller bodies of literature exist on interactive videodisc (Bosco, 1986) and distance learning (Kitchen, 1987; Moore, 1989; Nelson, 1985). Most of this literature finds newer technologies to be either equivalent or superior to conventional instruction with regard to student learning (Bialo and Sivin, 1990).

Computer-Assisted Instruction—Meta-analyses of studies at the elementary school (Kulik, Kulik, and Bangert-Drowns, 1984; Niemiec and Walberg, 1985) and secondary school (Bangert-Drowns, Kulik, and Kulik, 1985; Kulik, Bangert, and Williams, 1983; Samson, Niemiec, Weinstein, and Walberg, 1986) levels generally show a significant advantage for computer-assisted instruction. The relative advantage of computer-assisted instruction in these reports appears stronger for disadvantaged and low-ability students (Bangert-Drowns, Kulik, and Kulik, 1985; Samson et al., 1986) and for males (Niemiec and Walberg, 1985). When Clark (1985) reexamined samples of the studies included in earlier meta-analyses, however, he found that effect sizes were much smaller when the same teacher provided instruction in both treatment and comparison groups and were absent when instructional method was controlled (such that the study measured the effect of instructional delivery medium only). Effects were larger in shorter-term studies, suggesting that novelty effects boost performance with new technologies in the short term but tend to wear off over time.

Videodisc and Multimedia Technologies—Advantages of interactive videodisc over lectures have been reported (e.g., Nelson, Watson, and Busch, 1989). Fletcher (1990) conducted a meta-analysis of 47 studies comparing instruction via computer-controlled interactive videodisc (IVD) with conventional instruction in military training, industrial training, and higher education settings. On average, those who learned through IVD had achievement scores that were .50 standard deviation higher than those of students taught conventionally.

Constructivist Uses of Technology—The technology applications tested in the above studies were a far cry from the kinds of student-centered uses of technology most education reformers advocate. The empirical research comparing more constructivist technology interventions with conventional classrooms is much newer and more sparse, but there are some promising findings.

The *Jasper* series described above was evaluated during its experimental use in 52 classes in 9 states (Pellegrino et al., 1992). Classrooms using *Jasper* videodiscs (after 2 weeks of teacher training) showed significantly better performance than classrooms matched on demographic characteristics in terms of students' mathematical concept attainment, attitudes toward mathematics, and ability to plan their problem solving (Pellegrino et al., 1992).

Similarly, Project GALAXY found significantly higher performance in GALAXY classrooms on a variety of measures of scientific reasoning and problem solving. An evaluation of the science grade 3-5 curriculum in 15 GALAXY schools found that students in GALAXY classrooms gained twice as much as comparison students on performance assessments of classification skill and outscored the comparison group on two of four tasks involving experimentation. In GALAXY classrooms, students also appeared more skilled at working together in small groups, and teachers reported that they have more confidence in their ability to teach science and that more time was spent on science (Guth, Austin, Long, and Pasta, 1994).

Several studies have found positive effects of having students develop their own curriculum materials using hypermedia. When asked to draw "concept maps" of the Enlightenment, 11th-grade history students who had studied the period using a hypermedia corpus called ACCESS (American Culture in Context: Enrichment for Secondary Schools) had more information within their maps and used more abstract concepts to organize the information they had than did their peers who had not used the hypermedia materials (Spoehr, 1992). Similarly, Lehrer found that when ninth-grade students were retested a year after they had studied the Civil War, those who had developed hypermedia presentations had a more realistic understanding of the role of the historian, recalled more Civil War facts, and had more elaborated concepts (Lehrer, Erickson, and Connell, 1992).

Limitations of the "Horse Race" Paradigm

As logical as this comparative experimental approach may seem, the methodology and interpretation of these findings are highly problematic. When an innovation is tried, it necessarily includes not just a given technology medium but also particular instructional content and methods. As Clark (1985) points out, if you really want to assess the comparative effectiveness of the technology medium per se, you need to hold everything else constant. When Clark reexamined a sample of the CAI studies reviewed in earlier meta-analyses, he found that instructional method was equated in only half of the comparison studies. When those studies using the same instructional approach in both groups were analyzed separately, there was no effect of presenting the instruction via computer. In most cases, however, we are really not interested in whether there are effects of the delivery medium per se. Particularly when we want to understand how technology can support education reform, we want to change the content and the instructional strategy as well as the medium. In such cases, we need to look at the specific effects of various facets of the innovation and at the implementation process and how students and teachers use the technology, rather than simply comparing the two delivery media in terms of a single outcome measure.

On the dependent-variable side, issues can be equally thorny. Many studies, particularly those examining longer interventions, compare treatments in terms of outcomes on standardized tests, but these multiple-choice measures of basic skills may not measure the problem-solving processes and alternative interpretations emphasized in project-based technology programs. Equally biased are studies administering measures specially designed around the particular content and presentation format used in their technology project (Samson, Niemiec, Weinstein, and Walberg, 1986). Therefore, comparative studies are being superseded by more elaborate approaches, as discussed below.

Contextualized Research

Recognizing that student performance will be affected not just by hardware and software but also by the way a particular class or student uses the technology and the culture of the classroom, contextualized studies provide detailed descriptions of specific implementations.

For example, to study the effects of a program to help students develop a “community of learners” and create part of their own curriculum, Ann Brown and her colleagues found significant improvement on standard pretest and posttest measures (Brown, Ash, Rutherford, Nakagawa, Gordon, and Campione, in press). In addition, however, Brown et al. conduct detailed case studies on the conceptual growth of individual students in order to understand and to illustrate the factors that appear to be responsible for the observed gains.

Similarly, Riel (1989) coupled observations of students in a project involving an on-line “newswire” service and production of a student newspaper with data from their reading and writing test scores. Riel’s observations led her to conclude that the experience of editing others’ writing produces more improvement than does practice correcting one’s own mistakes and that students are reluctant to edit the work of their classmates but much freer to criticize and correct the work of a distant peer.

To determine the extent to which students of different ability levels participated in their Computer-Supported Intentional Learning Environment (CSILE), researchers at the Ontario Institute for Studies in Education found that students at all ability levels were involved equally and interacted effectively with CSILE, with particularly strong effects among the lower- and middle-ability groups (Bryson and Scardamalia, 1991).

It should be noted that these contextualized studies, which provide much more detail than is summarized here, seek to understand the complex interplay between an innovation, which is itself an amalgamation of many instructional features, and the particular culture of a classroom or characteristics of individual students. Such studies help us understand not just the effects that technology use can have on student learning but also the classroom implementation environment needed to realize technology’s potential.

3. STUDY AIMS, QUESTIONS, AND METHODOLOGY

As stated in Chapter 1, this study was designed to provide insights both into how technology can support constructivist learning activities at the classroom level and into the practical and organizational factors that promote or hinder technology implementations within schools. For this reason, research questions were specified at both the classroom and the school levels.

Research Questions

Classroom Teaching and Learning Questions

- What examples does the classroom offer of using technology to support long-term, student-centered projects?
- What does the technology add to the project that would not be there without it?
- What does the teacher see as the effects of the technology on students? On his or her own behavior and attitudes? On classroom dynamics?
- What do students perceive to be the pros and cons of using technology in the classroom?
- What observable evidence is available regarding the level of student achievement with technology, the degree to which technology prompts cooperation, and the effect of technology on the students' level of motivation?
- What technologies are used in the classroom and how much access does each individual student have in the average week?
- What are the dominant uses of technology in the classroom—would they be characterized as tutorial, exploratory, tool, or communication uses?
- What support does the teacher have for developing ideas for instructional use of technology and refining his or her skills in using technology? To what extent has lack of support been a barrier to the use of technology in the classroom?
- What kind of technical assistance is available? To what extent has lack of technical assistance been a barrier to the use of technology in the classroom?

School-Level Implementation Questions

- What factors led to the initiation of reform efforts? What role was played by (a) federal, state, or local school district policies; (b) producers of hardware, software, or other courseware; (c) business partnerships; and (d) research?
- What were the goals of the reform? How was it intended to differ from traditional or previous practice in terms of (a) curriculum; (b) instructional methods; (c) student motivation and self-concept; and (d) student and teacher roles?

- What resources were required to design, develop, and implement the reform? If extra funds were required, how were they obtained? What were per student costs?
- What factors and circumstances affected the design, implementation, and sustenance of the reform? What role was played by (a) federal, state, or local education agencies; (b) producers of hardware, software, or other courseware; and (c) business, foundation, or research partners?
- What was the actual impact of the reform on (a) curriculum; (b) instructional practices; (c) student motivation and self-concept; (d) student and teacher roles; and (e) student performance?
- How were outcomes measured? To what extent can the influence of the technology be separated from that of other portions of the reform?
- What features cut across successful programs? Why are these features important? What features are associated with less successful outcomes?
- To what extent have successful models been replicated in other classrooms, schools, or districts? What factors support or impede dissemination?
- What guidance can be given to other sites wishing to implement one of the reform models?

Overview of the Methodology

Site Selection

Given the resources to conduct case studies at just nine sites, the research team devoted considerable effort to choosing cases that would provide a range of worthwhile examples for other schools. We were quite aware that no site was likely to prove to be exemplary in all respects, and that all schools, including those that are pioneers, experience difficulties and unevenness in their programs. We looked for sites that had a history of using technology not for its own sake, but rather as a support for constructivist learning and a broader education reform agenda.

Further, both OERI and our research team felt that it was important to pull illustrations of exemplary instructional uses of technology from public school classrooms serving students from diverse backgrounds and from low-income homes. We sought to document the fact that technology-supported constructivist learning activities can unfold not just in affluent suburban schools but in classrooms facing all of the funding and social issues besetting so much of the nation’s education system.

We collected ideas for potential case study sites through a review of the literature, through discussions with practitioners and education technology experts at a national conference, from our project advisors, and from our own network of school and technology contacts. We conducted telephone interviews with nearly 40 potential sites to collect information regarding the following criteria:

- ***Potential for providing general lessons about the role of technology in educational reform.*** We looked for sites that could generate rich information about the design, implementation, and impact of technology applications in the context of educational reform. We gave priority to sites that appeared to be engaged in a cohesive effort directed at improving education for all students.
- ***Illustration of the roles of various players in education reform.*** To understand the roles of states, districts, and schools as well as those of the business community, parents, and foundations, we tried to obtain a set of sites that represented variation in the set of major "players" involved in bringing about education reform.
- ***Student population affected.*** Technology implementations aimed at promoting learning among economically disadvantaged students, and students of diverse ethnic and cultural backgrounds, were targeted. Technology is often used with disadvantaged students in ways that accentuate the differences between the instruction given the "haves" and the "have nots." Although many of the more constructivist uses of technology we were interested in have occurred most typically in schools serving relatively affluent populations, we sought out schools using technology in programs that challenge all students, including those whose backgrounds might have been regarded as putting them at risk of school failure in more traditional programs.
- ***Stage of technology implementation.*** Design and implementation issues can best be addressed by studying sites in various stages of implementation. Although we wanted sites with enough experience to be able to draw some conclusions about what was and was not working, we arranged for variation in the schools' length and intensity of interaction with technology.
- ***Grade-level focus.*** Since grade level affects the design, implementation, and impact of technology applications (reform has proved much more difficult at the secondary school level), we made an effort to include middle and secondary settings as well as elementary schools within the site sample.

Applying these criteria to the potential sites for which we had conducted phone interviews, we made recommendations to OERI and negotiated a final case study sample, described in Table 1. (The school names appearing in the table and throughout this report are pseudonyms.)

Table 1

CASE STUDY SITES

Site	Level	Student Body: Free/Reduced-Price Lunch	Student Body: Demographics	Setting	Region	Key Features
Bay Vista Elementary	E	25%	89% minority; 25% ESL	Suburban	West	State model technology school site for science
TeacherNet (Network of 462 schools)	All	Varies	Varies across schools	Includes rural, urban, and suburban	Midwest	Partnership of 54 school districts across 2 states participating in network activities
South Creek Middle	M	65%	60% low-income Hispanic	Suburban	Southwest	Reopened in 1991 as model restructured school with high level of connectivity
Nathaniel Elementary	E	85%	95% minority; 59% LEP	Urban	West	Inner-city school involved in classroom projects including communal databases for cooperative learning and video-supported science and language arts curricula delivered through satellite dish
Progressive	E	23%	Wide SES range; 61% minority	Urban	West	Charter school with team-taught classes, project-based instruction and 1 computer for every 2 students

Table 1

CASE STUDY SITES
(concluded)

Site	Level	Student Body: Free/Reduced-Price Lunch	Student Body: Demographics	Setting	Region	Key Features
John Wesley Elementary	E	100%	86% Hispanic including many children of migrant workers; 64% LEP	Suburban	West	Technology introduction initiated by teacher team working on curriculum and instruction as part of school's active restructuring effort
School of the Future	M	80%	Wide SES range; 67% male	Urban	North Central	Designed as "break the mold" school incorporating technology; course offerings designed around student interests
East City High (School-Within-a-School)	S	40%	35% African-American	Urban	Midwest	Apple Classroom of Tomorrow (ACOT) within urban secondary school
Maynard (School-Within-a-School)	M 4-6	77%	71% African-American; 27% Hispanic	Urban	Northeast	Mini-school provides students with extensive access to computer lab and wide area network resources

On-Site Activities

With the exception of the use of video to document our interviews and classroom observations, our data collection procedures followed standard qualitative procedures. Two-person evaluation teams visited each of the nine sites for a period of 3 to 8 days over a 2-year period. At each site, we did initial brief observations of a broad range of classrooms in order to pick two classrooms for more intensive observation and videotaping.[2] Our criteria for choosing these classrooms were a combination of the theoretical and the pragmatic—from the early discussions with administrators and teachers, we tried to select classrooms that were using technology in tool-like ways to support complex, student-centered activities. At the same time, we were constrained by schedules, trying to select classrooms that would be doing something interesting on their technology-supported projects on the particular days we would be present to observe them. These more intensively studied classrooms were typically observed over repeated days, sometimes on multiple visits. More extensive interviews were conducted with the teacher or teachers, and typically one of our two student focus groups was conducted with students drawn from this class. In addition, as our data collection proceeded, we found it useful to interview individual students or small groups as they developed or exhibited their technology-based work or demonstrated how they used particular pieces of software. We observed and videotaped classes, school activities, teacher meetings and training, and other key events related to technology use in these classrooms.

In addition to the classroom-based data collection, we interviewed a wide range of other school respondents, including principals, project coordinators, and school technology coordinators. Moving out from the school, we then interviewed representatives of other institutions that were pivotal in the school's reform effort. These might include district personnel, researchers, representatives from business partners, leaders from parent groups, or education consultants. Our final selection of respondents depended on the school's particular implementation history and its perception of the key players within it. For individual sites, we also interviewed a school board member, a union leader, and a state administrator.

Planning for Cross-Site Synthesis

National studies involving multiple sites require advance planning and structuring of the data collection effort so that information can be systematically collated and synthesized for cross-case

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2. The single exception was the "site" that was actually a network of over 450 schools. For this site, we visited four schools and selected a single electronic research class for more detailed observation and description. Hence, there were 17 classroom activities in our final sample of detailed vignettes.

analysis. To this end, we planned a strategy that included site visitor training, the use of interview guides for each type of respondent (e.g., teachers, principals, technology coordinators), development of debriefing forms for the school and classroom levels, and the use of qualitative analysis software (Seidel et al., 1988) to facilitate qualitative data analysis.

We used our research questions as a general blueprint for designing both interview protocols (lists of topics to be covered) and debriefing forms (case study outlines). The purpose of a debriefing form is to provide a standardized framework for writing a case study report. This is especially important when multiple sites and multiple researchers are involved. We used two debriefing forms for our study, one for schools and one for classrooms. The school-level debriefing form took a broad view that included a review of the educational context of the site; demographic information; educational indicators; history of educational reform at the site; levels of involvement at the district, state, and federal levels; history of technology applications, including incentives for use, when and how the applications started, technologies used, target grades and curricula, key school players, and key outside players; overview of the way the technology is used by students and teachers; implementation details, including problems encountered, strategies for overcoming barriers, and facilitators and costs; impact of the technology use on students, teachers, and the school climate and processes; the way the technology use is evaluated; and respondents' reflections and advice.

The classroom debriefing form was similar in scope but focused on what was observed in the classroom during the site visit. Site visitors were prompted to write about the classroom context, features of reform that they observed, the classroom activities that took place, the technologies involved (e.g., microcomputers, wide area networks, hypermedia, animation, simulation), how the technologies were used by students and teachers, and intended and actual benefits of the technology use from the perspective of students and teachers. The debriefing forms for our schools and classrooms are presented in Volume 2: Case Studies.

A special feature of our cross-case synthesis plan involved the use of software for qualitative data analysis, in our case, *THE ETHNOGRAPH*. The software facilitates the analysis process by searching for and retrieving data marked by code words or combinations of code words. It prints out text organized by the code or codes specified in a search procedure. The printout then can be assembled in a way that allows the researcher to read all the text pertaining to a particular topic, concept, or variable across all sites or a subset of sites. A critical step in using such software is the generation of a set of codes for labeling segments of text. We began the process of developing codes concurrently with designing the debriefing forms. Details of this procedure and a listing of our analytic theme codes are provided in Volume 3: Technical Appendix.

Software-Supported Cross-Case Analysis

After the majority of write-ups were complete, the research team members read one another's write-ups and met as a group for a full day to share impressions and begin the process of interpreting the findings from a cross-site perspective. We began by focusing on individual cases and then worked across cases. Our shared conceptual framework, exemplified by the debriefing form, helped to structure the discussion, but by this time, we were thinking beyond the debriefing framework to look for higher-order patterns and issues that we had not recognized when the debriefing forms were designed. We focused especially on successful sites and what made them so, and the apparent reasons some supposedly "exemplary" sites hadn't turned out to be so exemplary after all. As we generated observations about our sites, we began to identify potential cross-site themes and corresponding theme codes. The methodological volume (Volume 3) contains a full listing of theme codes, as well as the heading codes from the debriefing forms.

Once the debriefing forms were converted to ASCII files, the next step was the insertion of codes. Embedded heading codes were inserted on-line by clerical staff; theme coding and other more complicated coding were inserted by researchers on hard-copy printouts and then inserted into *THE ETHNOGRAPH* files by clerical staff.

Once all the codes were inserted, searches were run. A search pulls out all segments of text that are coded with the code word being searched. (Volume 3 contains examples of search output.) Multiple code searches can be done on all files or a subset of files, so that researchers have limitless ways to explore the data.

The search output then was organized into six major categories:

- Technology Implementation
- Technology Climate
- Curriculum Content and Technology Uses
- Reform Features of Technology Use
- Teacher Training and Outcomes
- Student Outcomes.

The search output filled four large notebooks. Within each notebook, the printouts were further organized by code word. For example, the Technology Implementation notebooks encompassed 29 codes beginning with HISTORY. Text coded with HISTORY was organized by site, after which the next set of printouts would appear. This way of organizing the printouts was selected because it enabled the researcher to read across sites while staying focused on a particular aspect of the technology application—in this case, the history of each implementation.

In addition to facilitating the consideration and elaboration of themes across the sites, *THE ETHNOGRAPH* also facilitated quick counts and status checks regarding the occurrence of selected variables within each of the sites. This provided an additional means for the researchers to verify and summarize their findings. For example, the researchers were quickly able to assess the number of classrooms within and across sites that reported specific intended benefits (e.g., higher-order thinking skills) and teacher-observed effects (e.g., increased student motivation, greater collaboration) in relation to the integration of technology. The findings of the cross-case analysis supported by *THE ETHNOGRAPH* are presented in Chapters 5 through 10.

4. CASE STUDY PROFILES

This chapter presents thumbnail sketches of the nine case study sites. Pseudonyms are used for schools in these sketches and throughout this report. The full case study reports for both schools and classrooms are available in a companion volume (Volume 2: Case Studies). Readers are referred also to our multimedia descriptions of schools and classroom activities available through the World Wide Web on the Internet (the URL for the project's web site is: http://www.ed.gov/pubs/EdReformStudies/EdTech/

Bay Vista Elementary School

Context. Bay Vista Elementary School is located in a working-class neighborhood of homes and apartments along the border between two Western cities. Many of the students' parents are employed in industries related to the nearby airport. Of the 575 students, approximately 25% are eligible for free or reduced-price lunch, and 11% are identified as limited or non-English proficient. Sixty-seven percent of the students are Asian/Pacific Islander; 12% are Hispanic; 11% are Caucasian, Non-Hispanic; 9% are African-American; and 1% are Native American. Nineteen certified teachers serve on Bay Vista's faculty. Although Bay Vista is in a modest neighborhood, teachers estimate that over 50% of the students have computers in their homes.

Reform History. The technology innovations at Bay Vista were initiated by a tightly knit core of teachers who were early computer users convinced of technology's capabilities to promote students' higher-order thinking. Bay Vista's principal supported the teachers' willingness to take advantage of district-offered training in technology and grant writing. After several teachers took a computer class in 1979, they applied for Chapter 2 funds to purchase a computer for the school. Impressed, the principal set the goal of getting as many students on computers as possible. The school pursued technology through the district's Computer Cadre, as well as through state funding for a project to analyze software for activities that would promote the thinking skills addressed in Bay Vista's problem-solving curriculum in grades 4-6.

By 1983, all 19 of Bay Vista's teachers were active computer users. Building on their technology experience and the science expertise of one of the teachers, Bay Vista successfully competed for a state Level II Model Technology Schools (MTS) grant in science. The program Bay Vista developed, Technology Optimizes Performance in Science (TOPS), extends throughout the elementary school (K-6). The grant supported a project coordinator position shared by two teachers, a central repository for science software and curriculum materials, special activities, and professional development.

Reform Features. Bay Vista stands out in the degree of coherence of its approach and its integration of technology across grade levels and subject areas. A significant influence has been the state curriculum frameworks that urge higher-order thinking, constructivist teaching and learning approaches, and cross-disciplinary projects. Bay Vista teachers have been active in many of the state reform initiatives, including the state science project and development and field testing of science and math portions of a statewide performance-based assessment system. Bay Vista teachers also participated in the state's Technology Leadership Academy for science and social science and the Educational Technology Summit. In keeping with state frameworks, the TOPS project emphasizes hands-on science and integration of science with other parts of the curriculum.

Although Bay Vista has not attempted major changes in its basic structure (such as multi-age grouping), the functioning and climate of the school have been significantly affected by TOPS activities. By supporting the project coordinator position and a project room, featuring an area set up for hands-on science activities (as well as a software library and 14 networked PCs), TOPS has provided opportunities for teachers to observe and support each other's work in conducting project-based and technology-supported activities. The technology coordinator may team teach a lesson with the regular teacher; alternatively, she may take over the class while the regular teacher observes a technology-using teacher at Bay Vista or elsewhere.

Bay Vista Elementary School (Concluded)

In a typical lesson, a third-grade teacher introduced her class to the topic of biological decay in a whole-class discussion format, using the chalkboard to write down key concepts. She reinforced these concepts with images and video clips from a laser disc attached to a large monitor (an apple decomposing and a graphic close-up of a dead rat swelling and exploding). A Micro/Macro video projection system was used to show living bacteria collected from classroom air molecules. On the next day, the theme was followed up in the project room, where the teacher and the technology coordinator conducted hands-on explorations of classroom bacteria.

Bay Vista classes have access also to computers in "mobile labs"—Macintoshes on wheeled carts. In one fifth-grade class, students worked on multimedia *HyperStudio* science and language arts presentations using word processing programs, microphones to record sound, draw programs or *Kid Pix* to create graphics, and a Canon Xap Shot Still Video Camera attached to a Macintosh to import photographs. While half of the 32 students collaborated in small groups at computers around the room's perimeter, the other half work individually at their desks. At the bell, teams of four students, quite serious about their charge, gingerly shepherded the computer carts safely to the next classroom, supervised by the "step monitor" who guided the teams down the classroom steps and made sure that a tarp protected the computers in the rain.

In general, the opportunities for teachers to observe one another have led to more consistency and connections across classrooms. Many teachers use the same group structures and role assignments for small-group lessons. Articulation within and between grade levels is reinforced by teachers' frequent references to the content and activities of other classes and grades.

Technology Supports. Bay Vista illustrates the strength of home-grown expertise. A core of teachers took it on themselves to become knowledgeable about computers and their instructional applications. With the support of the district, the staff have been aggressive and successful in going after state grants to fund the technology coordinator position and in-service training and release time. The commitment and ever-increasing knowledge of this core group overcame the trepidation of more timid colleagues and the shifting agendas of multiple principals.

Outcomes. In its Model Technology Schools Self Study, Bay Vista documents improved achievement in science content as measured by the Comprehensive Test of Basic Skills (CTBS) and on a test of basic process skills in science (BAPS). Increased motivation was noted when nearly all sixth-graders completed science projects, and 9 of 13 students won awards in the county science fair, when no students had even entered in previous years. Student surveys showed that 65% of students thought that technology had improved their problem-solving, writing, and reading skills. A majority also said that use of technology led to higher grades, more enjoyment of classes, and improved ability to work with others. Teachers reported that students appeared to take more responsibility for their own learning.

East City High School ACOT Program

Context. East City High School (ECHS) is one of 17 high schools in the 16th-largest district in the nation. Located in a working-class urban neighborhood, the campus is reminiscent of the film location for *Grease:* a three-story brick building, nearly 70 years old, with wide, locker-lined hallways. The school draws from a low-mobility population, with most graduates taking blue-collar jobs in the local area. The 87 ECHS faculty are nearly all veteran teachers, and turnover is low. Of the 1,176 students in ECHS, 41% receive free/reduced-price lunch, 15 to 20 students are designated as LEP or NEP, and 86 receive special education services. Thirty-five percent of the students are African-American. ECHS's technology program is one of the original five Apple Classrooms of Tomorrow (ACOT). Nested on the school's third floor, the atmosphere of the ACOT program is charged with excitement, due, perhaps, to the nonstop parade of visitors, teams of intense teacher observers, the raucous interaction of teenagers with each other and the ACOT staff, or the nine ACOT staff themselves as they share strategies, problem solve, juggle schedules, adjust, and readjust. The ECHS ACOT program serves 120 students at grades 9-12.

Reform History. ECHS faculty cite their Effective Schools Program as the main schoolwide reform initiative. This program has included site-based management and institution of a number of innovative practices, such as interdisciplinary team teaching, common planning times for a subset of teachers, and a thematic approach and cooperative learning for vocational education students, on a limited trial basis. The ACOT program, however, is the centerpiece of ECHS's reform efforts.

The primary incentive for participating in the ACOT program was the opportunity to fully equip a number of classrooms with the most advanced Apple technology, at no cost. The program had its origins in 1983, when Apple's regional office became interested in ECHS because of its popular "Summer Tech" program, sponsored by the district with support from local universities and businesses. The office encouraged the Summer Tech instructor to submit a formal proposal to Apple's newly forming ACOT program, established to study the impact of a high-technology environment, in which every student had a computer at school and at home. The Summer Tech instructor and the district supervisor of technology proposed a project for ECHS, focused on interdisciplinary team teaching (English/social studies, math/science) and the use of the computer as a tool.

By the summer of 1986, the four original, interdisciplinary team members found themselves launched on the new venture. The team had decided to request Macintosh computers rather than Apple IIs because of their greater power. At the time, this decision seemed like a real trade-off because there was no instructional software for the Macintosh. This situation was serendipitous in forcing the ACOT teachers to think innovatively about how the general tool software available for the Macintosh—*MacPaint, MacWrite, MacDraw,* and *Excel*—could support educational activities.

For each of the next four years, the program added a new class of approximately 30 ninth-graders. In the summers, the ACOT teachers were flown to California for joint training with other ACOT site teachers. The summer training focused on constructivist teaching approaches rather than on technology per se. In time, the teachers began to work together in ways that integrated their subject matter more meaningfully and used the technology in new ways.

Reform Features. The ACOT program is designed as a school-within-a-school. Students rotate among four ACOT classrooms, each with 36 networked computers. The

East City High School ACOT Program (Concluded)

nine ACOT teachers use an interdisciplinary team teaching approach, incorporating the use of technology as a natural part of teaching and learning. Their major contribution has been demonstration of the instructional value of using general computer applications to support student work. With this approach, the teacher does much more coaching of individuals and small groups rather than lecturing.

Collaborative planning is a key part of the program. ACOT teachers are given every afternoon for common planning and are excused from noninstructional duties. In partnership with Apple, the school has recently implemented a Teacher Development Center (TDC) to allow teachers and administrators from other schools to observe the program for a full week and receive hands-on training in instructional uses of technology and in collaborative, interdisciplinary, constructivist teaching approaches.

A large amount of technology supports the ACOT program. For student use at home and at school, there are 160 Mac Plus computers. Each ACOT classroom contains 36 computers, including 8 networked Macintosh IIs, as well as numerous multimedia peripherals and software available through local and wide area networks. Most of the software available is used by students and teachers as a tool for accomplishing tasks.

For example, a social studies teacher and an English teacher designed a unit on China. The students visited an exhibit at a local museum, accessed a videodisc of the artifacts in the exhibit, a database about the artifacts along with the curator’s notes, and dozens of informational books on Imperial China. Students worked in groups of three to explore the videodisc and database to come up with possible topics for an in-depth exploration, culminating with a Chinese New Year celebration. Groups were also allowed to decide how to present their material using videodiscs, scanners, MacRecorders, computers, and cartridge drives. Students have also authored and pressed two of their own videodiscs, one describing their city and one presenting an in-depth study of eight French and Spanish artists and their work. Other examples of the use of technology as a tool included students’ resumes, newspapers, multimedia art projects, and video portfolios for prospective employers and college admissions personnel.

Technology Supports. The principal way that the ACOT teachers have dealt with obstacles is through collaborative problem solving, bolstered by generous amounts of training and release time. Apple has provided ongoing technical assistance and advice on an as-needed basis. Faculty from the state university have also supported the program. Initially the ACOT coordinator had difficulty in maintaining the hardware, but eventually he became a certified Apple technician. More importantly, the district recognized the burden and arranged for on-site maintenance.

Outcomes. Teachers reported improved student communication, reasoning, information retention, collaborative skills, and self-concept. None of the ACOT teachers mentioned test scores as appropriate measures of ACOT outcomes. All of the ACOT teachers talked about dramatic changes in their teaching philosophy (changing expectations for students, relinquishing the need to be the “expert,” comfort with not “covering” all the material), methods (interdisciplinary, team teaching, constructivist, cooperative learning), and dispositions (flexibility, increased willingness to “play” and “experiment”). An independent evaluation of all the ACOT sites (Baker, Gearhart, and Herman, 1994) found that students did as well as comparison groups on measures of basic skills while also acquiring new skills. In addition, there was some evidence of positive effects on composition skills, particularly for the ECHS ACOT.

John Wesley Elementary School

Context. Located in an agricultural area of a Western state, John Wesley Elementary School is bounded by open fields on one side and recently built residential housing on the other. The school serves 856 students in grades K-6. The children come from low-income families, many with parents who are migrant farm workers. According to the school's recent self-study, about half of the students arrive from Mexico with little or no formal education. Spanish is the primary language for 95% of the school's students, and 64% have limited proficiency in English. One-third of the students qualify for migrant education services. The classrooms are housed in multiple buildings of the "indefinite temporary" variety. Notices and posters appear in English and Spanish. In 1992 and 1993, 100% of the students qualified for free or reduced-price lunch. Ninety-five percent of the students are Hispanic; 2% are Asian/Pacific Islander; 2% are Caucasian, Non-Hispanic; 1% are African-American; and fewer than 1% are Native American. It is estimated that fewer than 1% of the students have computers at home. Thirty-one teachers and 4 resource teachers serve on the faculty.

Reform History. John Wesley opened in September 1981 with what the district administrator described as an "enthusiastic corps of teachers" that included teachers "with the ability to take a leadership role." In 1988, John Wesley was given the opportunity to participate in a Packard Foundation-sponsored science improvement program. The program promoted thematic instruction around science topics. Requirements for participation included having a third of the teachers commit to active participation and the other teachers promise not to undercut the change effort. In subsequent years, more teachers signed on, and by 1995, 98% of the teachers were involved.

In 1990, another major impetus for reform came when the district superintendent made contact with the president of Pacific Telesis at a Business Roundtable meeting. The Telesis Foundation was looking for school partners for joint educational reform activities. The superintendent encouraged John Wesley's successful application for funding. The program initially emphasized site-based management and the development of a detailed 8-year plan. State school restructuring planning and implementation grants in 1991 and 1992 gave further support to the school's reform efforts.

John Wesley's reform plans did not start with the idea that technology was a key. It was during the process of developing their proposal for a school restructuring grant that one of the teacher teams set up as part of site-based management began to think about the potential of technology to support hands-on learning and the kind of critical thinking and problem-solving skills they were trying to foster. A resource room teacher who was accustomed to using computer software with special education students became a facilitator and advocate. The school then began using grant money to acquire equipment.

Reform Features. John Wesley is somewhat ahead of the technology use of the other schools in its district, but not dramatically so. The extent of teacher decision-making and the way technology is integrated with an overall education reform philosophy are noteworthy, rather than the amount or sophistication of the technology per se.

In a fourth-grade class, for example, students worked on a thematic unit on whales and marine life. Working in collaborative groups, students selected five mini-projects or "inquiries" that allowed for independent decision-making over an extended period.

John Wesley Elementary School (Concluded)

Activities included creating maps depicting the migratory patterns of whales and using word processing to support letter-writing campaigns to groups such as the International Whaling Commission and Greenpeace and to produce research reports. Students used interactive, exploratory software to browse through data cards to gather information on different types of whales, go on simulated whale watches, take "pictures" of whales, listen to whale songs, and track migratory patterns. To the mournful sounds of humpback whales, one group choreographed a whale dance depicting the slow-motion movements of a whale underwater. In this unit, the teacher's role was one of coach—to facilitate collaborative problem solving, monitor progress, offer feedback and guidance, and orchestrate the use of materials and tools.

In general, John Wesley's computer resources are allocated to individual classes rather than to a computer lab. More computers are in upper-level classes, but all teachers have access to a mobile Mac lab and multimedia center. Word processing, especially the Learning Company's *Bilingual Writing Center*, is the most common computer use. Some classes use exploratory software such as *SimAnt* and math/science software that allows students to manipulate and predict the speed of airplanes and cars.

Professional development in the thematic science curriculum occurs in collaborative planning sessions. The teachers meet monthly with a coach, and teachers support each other—sharing successes, failures, lessons learned, and newly discovered resources.

Technology Supports. Limited technical support appears to have been the largest technology implementation problem at John Wesley. Staff report difficulties in selecting hardware and software, maintaining systems, and lack of time and strategies for teacher training and support in the instructional use of technology. The introduction of take-home portable computers for teachers on the condition that they attend training sessions and use the computers in their classrooms greatly increased the use of technology among teachers in 1994. Now (school year 1994-95), network and e-mail facilities have become available, and a school technology mentor devotes a half day a week to helping teachers with technology problems and to assisting with integration of technology into the curriculum.

Outcomes. The teachers feel that standardized test scores are not good measures of what they have accomplished with their students. Scores have fluctuated from year to year and grade to grade, ranging between the 35th and 50th percentiles in math and between the 30th and 45th in reading. Although the school's interdisciplinary program is not targeted at improving scores on standardized tests, a drop in scores in 1991-92 was a disappointment, softened by better-than-expected scores in 1992-93. Recent data show that those students who stay with the school for 2 years or more show growth on state standardized tests. The school is actively involved in developing alternative assessments and supportive of the state's performance-based assessments in science. Students' acquisition of technology skills has varied according to the teachers they have had. One teacher said that collaborative technology-enhanced projects have helped students to assess each other's skills (e.g., who is strong in developing ideas, writing, speaking) and learn how to make appropriate task assignments. The project coordinator attributes the high attendance rate at John Wesley to the whole restructuring effort rather than to technology per se.

Maynard Computer Mini-School

Context. The Maynard Computer Mini-School is a school-within-a-school consisting of eight classes, spanning grades 4-6. The Computer Mini-School occupies the fourth floor of a grades 3-6 elementary school located in a large Northeastern city, not far from a major private university. Most of the students come from a neighboring public housing project. The school building, constructed in 1925, shows many signs of age and decay on the outside and in the corridors, but large windows and fresh coats of paint make the classrooms themselves quite cheerful. Hallways are lined with colorful displays of children's artwork and writing. The mini-school serves 171 of the school's 713 students. Demographic data are not maintained separately for the mini-school, but in general its composition reflects that of the school as a whole: 77% of the school's population is eligible for free or reduced-price lunch; 6% were designated LEP; and 8% were classified as special education in 1992-93. Seventy-one percent of the students are African-American; 27% are Hispanic; 1% are Asian/Pacific Islander; and fewer than 1% are Caucasian, Non-Hispanic and Native American. It is estimated that fewer than 10% of the students have access to computers at home.

Reform History. In 1987, the computer teacher and several others at Maynard began working with a nearby college of education on a project called Earth Lab. Funded by the National Science Foundation, the Earth Lab project supported collaborative science investigations by elementary and middle school students with curriculum materials and a network designed to support long-term student projects. The project funding enabled the school to obtain additional computers and set up a local area network with a file server so that students could maintain their project work in special folders or "workspaces" set up for group activities. Once they became accustomed to using the network in this way to support Earth Lab collaborations, the students and teachers began setting up folders for other school activities, such as the school newspaper.

In 1990, Maynard's computer teacher and six classroom teachers asked the administration for permission to set up a mini-school to give students a more coherent program, reduce class size, and take advantage of the computer network technology. The teachers agreed to give up their preparation periods in return for increased authority over the design of their instructional program and smaller class size (20 students vs. 32 in regular classes). In the fall of 1990, the Computer Mini-School opened. In 1992-93, two more classes were added to the mini-school.

Reform Features. The most striking features of the mini-school program are extensive access to network and software tools to support communication and research and the smaller, more coherent classes, mostly co-located on a single floor. In contrast to the rest of the school, where student movement is strictly controlled, mini-school students move back and forth between their regular classes and the Computer Room, where they go to conduct research and work on assignments for their classes. Each mini-school student has an electronic mail account, and students use them to communicate with each other and with distant "pen" pals and individuals who can help them with their research (e.g., students studying Ireland contacted a university student in Dublin for a firsthand report of the kinds of jobs and sports interests prevalent in that country).

Each mini-school classroom is scheduled into the computer lab for two 1-hour periods weekly. These whole-class sessions are planned with the teacher to integrate the technology into the ongoing curriculum. The computer teacher takes primary responsibility for instruction, with

Maynard Computer Mini-School (Concluded)

the classroom teacher assisting and overseeing the management of the class. Computer classes often begin with a brief period of instruction, followed by individual or collaborative student work at the computers. For tasks that involve a series of new procedures, students are given worksheets providing step-by-step instructions, with spaces for the instructor to “sign off,” indicating that the student has completed each step correctly.

Students learn to use the Internet to gather information from outside resources when conducting research. During our site visit, students studying other countries for a multicultural festival accessed the Trinity University (Dublin) home page, sent e-mail to Irish university students, and searched an on-line CIA database for information about Brazil.

The Computer Room is kept open from 8 am to 6 pm daily. In addition to the 2 hours in which their entire class is scheduled into the Computer Room and drop-in opportunities during class time, approximately half the students come regularly during recess or before and after school. During these self-selected times in the Computer Room, some students work on assignments, while others correspond with network pen pals, or play with game-like software. Teachers also come into the room to use the computer resources. After-school activities we observed included a sixth-grade non-mini-school teacher using software to produce a Kenya banner for the multicultural festival; a sixth-grade mini-school teacher working with three students on a menu for the Mexican food they would serve at the same festival; three students showing their fourth-grade teacher how to get into her electronic mail on the network (a big breakthrough for this “technophobe”); two fifth-grade girls working independently on their country reports on Ireland; and a sixth-grade teacher consulting with the computer teacher about whether she could obtain the weather from all their different countries on the day of the festival.

Technology Supports. The computer teacher manages the mini-school’s technology and educational applications. He makes it a point not to push teachers, yet articulation between the Computer Room and regular classrooms could be enhanced if more teachers were interested and had confidence in applications other than word processing. Lack of time for in-service training on instructional uses of technology is a major impediment. The mini-school teachers do not have prep periods, and the few in-service days available to them are mostly taken up with other activities.

Outcomes. Although data have not been maintained and analyzed systematically, a special analysis performed by Earth Lab researchers after the mini-school’s first year concluded that mini-school students perform better than their peers in the rest of the school on standardized tests, particularly in math. The researchers attribute the higher achievement level to the greater cohesiveness of the mini-school program, an attribute that is supported by, but not solely attributable to, the use of technology.

A classroom teacher asserted that activities involving the LOGO programming language helped her students develop better understandings of mathematical concepts and procedural, logical thinking. The principal pointed out that the Computer Mini-School students typically do well in interschool competitions, such as poetry contests and science fairs. It is clear that many of the students are proficient with basic tool applications; some have developed more sophisticated skills corresponding to their areas of interest. Many students take pride in the fact that they are more proficient in the use of technology than most adults.

Nathaniel Elementary School

Context. Located in a low-income neighborhood of a Western city, Nathaniel Elementary School serves 1,400 students in grades K-6. The area surrounding the school has a reputation for crime, drugs, and gang activity. An influx of immigrants each year brings the school an increasing proportion of limited-English and non-English-speaking students.

Built in 1939, Nathaniel's main building houses nine regular classrooms and four half-sized classrooms for special education and resource labs, including a computer lab. In addition, 18 portable classrooms are scattered across a concrete yard. Students are organized into both single- and mixed-grade units. Approximately 85% of Nathaniel students are eligible for free or reduced-price lunch; 59% are designated as LEP or NEP; and 70 students are in special education. Fifty-seven percent of the students are Hispanic; 19% are African-American; 23% are Asian/Pacific Islander; and 5% are Caucasian, Non-Hispanic. Nathaniel's staff includes 44 certified teachers (6 of whom work half time, teaching in pairs) plus special education teachers and aides. It is estimated that 1% or fewer of the students have computers at home.

Reform History. Nathaniel has had a long-standing commitment to educational reform. In 1987, the school began implementing programs that addressed the social and affective needs of students, specifically to: (1) make education more relevant to the population that they were serving, (2) prepare students for the 21st century, and (3) address the "horrendous dropout rates of children of color." A conflict management program was introduced, followed by a program teaching skills for working in cooperative groups. Together, these programs are credited with reducing discipline problems within the school, facilitating cooperative learning skills schoolwide, and laying the groundwork for other new programs.

Within its district, Nathaniel is one of the most active schools in applying for and receiving special project grants and funds. In the spring of 1992, Nathaniel became one of 14 Demonstration Schools within the district, receiving intensive resources from the district's desegregation funds to implement technology-supported schoolwide change. The program components included adoption and implementation of a schoolwide improvement model, 10 to 15 days of additional staff development, extended instruction for students at risk (20 days of additional instruction), and integration of technology into the curriculum. Specific technology-based activities have included serving as a test site for Computer-Supported Intentional Learning Environments (CSILE) and for the Project GALAXY.

Reform Features. Education reform and technology implementation have evolved hand in hand at Nathaniel. Staff members feel strongly that technology expertise is critical to the future success of students and that schools serving lower-SES students should provide the technology tools more readily available in affluent communities. Technology use by students began in 1983, with an Apple IIe lab (18 computers) funded with state and federal funds. In 1990, Nathaniel was one of three schools in the district to receive 45 Mac LCs. With three computers in their classrooms and the available applications, 15 teachers began using the computers with their students, primarily for word processing, drawing, and math. A take-home computer program and computer-based adult literacy class provide parents with technology access and training. Special projects, such as CSILE and GALAXY, were brought in largely because they fit in well with the school's ongoing reform efforts.

Nathaniel Elementary School (Concluded)

At the heart of the CSILE project, which is used in a variety of subjects, is the use of technology to support collaborative problem solving, group investigation, and knowledge building. CSILE software consists of a communal database, with text and graphics capabilities, which students in the participating classrooms access through a local area network. In four CSILE classrooms, students spend at least a half hour per day entering new information, theories, and opinions into the database. They comment and critique one another's work on-line, locate information, and construct links between related entries. Students have created an ongoing, on-line literature circle—sharing information within and across classrooms about books they have read. Students also have engaged in math problem solving—posting solution strategies in graphics and text.

In two grade 5/6 classes, CSILE has been used in an interdisciplinary project in which students in each class invented their own hypothetical ancient culture, produced and buried artifacts for that culture, and then conducted an archeological dig on the other class's site, making inferences about the culture from the materials they uncovered. Students in each of the classes used CSILE to communicate across groups working on different aspects of their culture and built large databases describing and illustrating the language, food, art, and religion of their hypothetical civilization.

In the Project GALAXY, funded in part by Hughes Aircraft Company, students viewed weekly video segments (in Spanish, English, or closed caption) on science or language arts topics. Each segment presented issues and problems for students to solve. Between video segments, the students worked in collaborative groups on related projects and shared their responses and research findings with other classes through facsimile machines linked to the GALAXY Institute via satellite. Each school was paired with partner schools (in Florida, Massachusetts, and New York) for ongoing videotape and faxed message exchanges.

Technology Supports. Nathaniel has a full-time on-site technology coordinator who runs the computer lab, participates in teachers' planning, troubleshoots technical problems, assists with software choices, and trains teachers and students in the use of particular technologies. During 1993-94, two graduate research assistants provided technical and curricular support for the CSILE project, preventing or correcting the kinds of system failures and training problems that impeded progress during the first 2 years of field testing. The Project GALAXY field test experienced some technical difficulties in its first year, as well, particularly with the facsimile exchange. Nathaniel has a Project GALAXY coordinator who acts as liaison between the teachers and the GALAXY Institute.

Outcomes. The district Assistant Superintendent of Curriculum and Instruction reports that Nathaniel's test scores are "on par" with the rest of the district. She adds that Nathaniel has a much smaller percentage of students who are retained or suspended, which she attributes to the school's focus on conflict management and other programs addressing the social/affective needs of the students. Nevertheless, average standardized test scores ranged between the 19th and 30th percentiles for sixth-graders (in 1992), considerably higher than the scores of second-graders (7th to 14th percentiles), but still far below what faculty and administration feel the students have achieved academically. The school has implemented portfolio assessment in some classrooms, and the district is examining alternative forms of assessment.

The Progressive School

Context. The Progressive School is located near the juncture of two freeways in an urban area of a Western city. The school is housed in a permanent administrative building and a series of temporary buildings squeezed onto the campus of another elementary school. Although the administrative building looks its age, it houses a multimedia room and a sound studio that have been renovated and contain up-to-date computer and video equipment. The temporary buildings are long "boxcar" style rectangles (double trailers), each housing a cluster of 64 students and two teachers.

The floor space within a typical Progressive School classroom is taken up by groups of desks containing built-in Macintosh computers underneath Plexiglas tops. The school's 384 students, ages 6 to 12, are assigned to multi-age clusters, each encompassing an age span of 2 to 3 years. (A kindergarten class was added in 1993-94.) The clusters overlap, and some students stay in a given cluster for more than 1 year. In 1992-93, 23% of the school's students were eligible for free or reduced-price lunch; 11% were designated LEP or NEP; and 55 were eligible for special education services. Thirty-nine percent of the students are Caucasian, Non-Hispanic; 23% are African-American; 20% are Hispanic; 17% are Asian/Pacific Islander; and fewer than 1% are Native American. Approximately 32% of the students have computers at home. The staff consists of 12 full-time teachers, a magnet coordinator, and 4 part-time teachers.

Reform History. The Progressive School was started in 1977 by a group of parents and teachers who wanted an alternative to the "back-to-basics" approach that dominated the district at that time. The group wanted to start a school based on the principles of Jerome Bruner and the practices of the British infant schools. Their desire coincided with the decision of the district to set up a series of magnet schools to comply with court-ordered desegregation. Students are selected at random within a set of geographic and ethnic strata. From the beginning, the school stressed many of the concepts now popular in the education reform literature—active learning, thematic instruction, and multi-age groupings. In addition to general and desegregation funds, the school has received major contributions of equipment and staff support from Apple Computer.

The teachers believe that technology can provide a bridge between the totally physical, multisensory environment of young children's learning and the textbook environment of conventional classrooms. They emphasize software applications to give students tools to create things rather than instructional software that delivers drills or facts. The serious introduction of technology began in 1986, when Alan Kay, an innovator in human-computer interface design and Apple research fellow, selected the school as the site for his research. In the first year, the school tried a computer lab, but teachers objected to it because it separated students from them. Over time, Apple placed approximately 30 computers into each cluster classroom of 64 students. Most of the computers are recessed into specially designed tables that can be used for other student work when the computer is not needed.

The Progressive School had a history of getting district waivers for its curriculum and methodology. Rather than continue to get waivers on a piecemeal basis, the school chose to apply to become one of the state's first charter schools and received this designation in March 1993. As a charter school, the Progressive School has a mandate to experiment, yet it will continue to have the district take responsibility for things like liability, physical plant, and supplies so that the staff can concentrate on their internal organization and teaching. The school has

The Progressive School (Concluded)

selected a set of student outcomes on which to be judged and will be working with a nearby university on developing performance-based assessments.

Reform Features. The school's multidisciplinary "spiral curriculum" centers around the theme "man's survival in the environment." Each cluster takes a different slice within this central theme, combining different disciplines in building concepts.

The City Building project, undertaken as part of the City Environment theme for a grade 3/4 cluster, illustrates how multiple subject areas are woven into the technology-supported curriculum. Neighborhood teams plan and construct scale models of portions of a future city for their locale. City commissions set policy and conduct studies congruent with their mission. One year the building and safety commission, for instance, designed buildings to withstand earthquakes, while the transportation commission conducted experiments in energy and movement and the environmental commission studied water and ecology. Math is integrated through activities such as using the *Powers of Ten* videodisc and building their structures to scale, calculating the number of housing units needed based on population estimates, working on city budget issues, and programming animation sequences within *HyperCard*. In the 1993-94 school year, *SimCity* was incorporated as a planning and feedback/evaluation tool for neighborhood teams. Students use graphics and word processing software as they document their activities on a history wall and in commission reports. They select and create appropriate photos, three-dimensional models, illustrations, animations, and video segments for use in presentations and displays. Oral language skills are developed as students present and negotiate their viewpoints within their city-building teams.

Technology Supports. Apple provided the school with an extraordinary measure of support. In addition to the computers, CD-ROM and laser disc players, networking, and other technology, the corporation supported a full-time technical support person and a portion of the time of several other staff members who provided assistance with technology activities through the end of the 1992-93 school year. During this 6-year period, Apple also paid the school's teachers as consultants over the summer and winter breaks, during which time the teachers were able to receive coaching on technology use and spend time developing materials for use in their classrooms. During the 1993-94 school year, Apple supplied $50,000 in funding and continued to support one technical support position. It also trained six teachers in computer maintenance. Apple has indicated the intention to donate $25,000 to the school for the next year but will no longer supply an on-site technical staff person. The company would like to maintain an affiliation with the school but discontinue major financial support.

Outcomes. Historically, the school has had 500-600 applicants a year for its 50-60 slots for new children. After getting extensive publicity for becoming one of the state's first charter schools in the spring of 1993, Progressive received over 800 applications for the 1994-95 school year. The school has traditionally shown good test scores, especially given the economic diversity of its student population. On the 1994 administration of a state performance-based test, for example, Progressive had the third-highest scores among elementary schools in its large urban district. Many teachers have mentioned the effect of technology on student self-esteem and motivation. A number of the teachers believe that technology helps students from diverse backgrounds excel. Several teachers reported that technology promoted their students' willingness to edit and revise their writing. Parents are enthusiastic supporters; many volunteer time and donate money.

The School of the Future

Context. The School of the Future, a magnet middle school, occupies a former YMCA building on the downtown waterfront of a Midwestern city. The site features a variety of technology-supported learning spaces used for different purposes (e.g., cooperative learning areas, computer labs, classrooms with tiered seating and Discourse Systems, an Integrated Learning System lab, an independent study area, a video production studio). Every classroom is equipped with a telephone and a teaching station that includes a Macintosh linked to the school network and a video monitor to display in-school broadcasts and VCR or videodisc presentations. The building is simple on the outside; the inside is modern, attractive, and neat, but with an unusual lack of student artwork or other wall displays (except at student exhibition events). The School of the Future's downtown location has enabled it to offer a variety of off-site learning opportunities. Courses have been conducted at the science museum, the historical center, the state museum of art, and local cable-access studios. The School of the Future serves 170 students in grades 4-8; 80% are eligible for free or reduced-price lunch; 8-9% receive special education services. Fifty percent of the students are Caucasian, Non-Hispanic; 30% are African-American; 11% are Asian/Pacific Islander; and 9% are Hispanic. There are 9 certified teachers on the faculty. Approximately 20% of the students have computers at home.

Reform History. Built from the ground up as a "fundamental redesign of the way we deliver educational services," the School of the Future was conceptualized as a "high tech, high teach, high touch" program in which students would engage in a combination of computer-supported, teacher-led, and collaborative project-based learning activities. Stimulated by a speech by Al Shanker noting the failure of traditional education, a district administrator organized a collaborative effort involving a series of local partnerships including the local teachers' union, a nearby university, an artificial-intelligence software developer, and a number of hardware and software vendors. The School of the Future opened in the fall of 1989 with grades 4 through 6 (grades 7 and 8 were added in 1990 and 1991, respectively) and one of the ethnically most diverse student populations within the district. Over 65% of the students were male—an unintended outcome attributed by various observers to a differential interest in technology or to the fact that the school was viewed as an alternative for students having academic or behavioral difficulties in more traditional programs.

A unique (but ultimately divisive) aspect of the school was a two-tier staff structure. A lead teacher and three associate teachers held year-round, higher-salaried positions and had responsibility for developing the school's curriculum. Other teachers added in the second year were designated as "generalists" and had regular 9-month appointments, lower salaries, and less input into school decisions and curricula. At the close of the 1992-93 school year, the school district discontinued the year-round positions, and the three remaining members of the original lead staff transferred out. By the spring of 1994, the School of the Future was having trouble maintaining enrollment, and some informants blamed the district for using the school as a "dumping ground" for students who had failed to fit into other schools.

Reform Features. The School of the Future was built on a philosophy of individualized instruction, with students being responsible for their own learning. Other than required time working on basic skills in the Integrated Learning System (ILS) lab, students were to design their own educational programs ("Personal Growth Plans") in consultation with their advisors and parents. The concept called for doing away with textbooks and developing courses around the

The School of the Future (Concluded)

particular interests of students. Use of out-of-school resources, such as museums, science centers, and internships at work sites, was another important component of the design. Students were organized into “advisories” that stayed together during their School of the Future careers; most courses were open to the full age range of students (9 to 14).

Technology has played multiple roles at the School of the Future. A Discourse System, designed to collect and tabulate student responses to teacher closed-ended questions, has been adapted for use in brainstorming sessions. The initial reliance on the ILS lab as “insurance” that students would acquire basic reading and mathematics skills has given way to a perception that laboratory and regular classroom activities need to be more closely linked. The most successful and enduring use of technology at the School of the Future has been as a tool to support student projects and investigations. For research projects on topics such as sea turtles or an Indian tribe’s protests against spent fuel rods on their land, students might photocopy written material to highlight for later reference, gather information on CD-ROM, conduct a telephone interview with an informant, use the Macintosh Writing Lab to prepare text portions of their presentations, or use the scanner, the interactive videodisc, or *HyperCard* in the Multipurpose Mac Lab or the Media Lab to incorporate graphics, sound, or animation. This high level of self-selected access to such a wide array of equipment results in what one School of the Future teacher described as “technology-hungry” students who are skilled and comfortable in using technology in their work as a matter of course. The School of the Future’s use of technology has been part of what brought it national publicity and has led to increased opportunities for the staff to participate in professional activities outside the district, including national education reform activities and conference presentations.

Technology Supports. The ILS and Discourse System technologies initially selected by the leadership team before the school opened did not match the instructional philosophy of teachers hired subsequently. Most of the teachers came with little knowledge of technology. In the third-year evaluation report, teachers reported lack of time as the critical factor in preventing them from becoming more familiar with the technology and software. The part-time technology coordinator has been disappointed by the poor teacher turnout when he offered in-service training.

Outcomes. Standardized test scores, especially in mathematics, showed declining performance relative to national norms over the School of the Future’s first two years. An independent evaluation revealed that performance—at least in math—increased relative to national norms for lower-performing students while dropping slightly for above-average students. Given the lack of match between the School of the Future’s curriculum and approach and the tests, the positive effects for lower-performing students are encouraging. In addition, the staff and the district have taken steps to strengthen areas in which their program was not providing adequate instruction for all students. Staff have moved also toward getting portfolio assessments in place. Many parents, however, had become nervous about the amount of freedom given to students and the failure to include certain elements in a required program. Many students and teachers left during the first few years. Despite the fact that initially there were 500 applicants for some 160 openings, the School of the Future now has to actively recruit students (after negative local press about lower standardized test scores). Nevertheless, there is a set of students and parents for whom the school’s nontraditional approach has been very motivating and successful.

South Creek Middle School

Context. South Creek Middle School is located on 21 acres in an outlying area of Southwestern city. A freeway runs through the district, separating affluent, single-family homes from areas of multi-family units housing an increasingly poor, increasingly ethnic population. Originally a middle-class suburban junior high school, South Creek was closed in the mid-'80s because of declining enrollments. The school was renovated and reopened in the fall of 1991 as a technology-rich model school.

Built around a two-story library/media center, the school contains a series of "areas," each containing five adjacent classrooms for core courses for a set of students who take most of their classes together. Each area also contains a well-equipped office for the four or so teachers who use it, with desks, phone, scanner, printer, and computer. Special, separate classrooms house art, foreign language, music, band, and industrial technology classes, with individual offices for teachers. The school and grounds are immaculate—no graffiti, no litter. To avoid a hard, high-tech look, the staff have brought in country folk art and crafts to decorate the halls and offices. South Creek has over 400 networked computers, with 5 to 6 in regular classroom and close to 30 in each of several labs.

Of the approximately 641 students enrolled in grades 6-8, 65% receive free or reduced-price lunch; 25% are classified as LEP or NEP; and 11% receive special education services. The majority of the student population are Hispanic (59%); 29% are Caucasian, Non-Hispanic; 6% are African-American; and 6% are Asian/Pacific Islander. Only about 5% of the students have computers at home.

Reform History. South Creek's redesign demonstrates the effectiveness of careful planning. When rising enrollments required adding another school, the district superintendent argued that reopening an old school was more cost-effective than building a new one. Believing that technology would be part of students' futures and a necessary addition to teachers' capabilities, he decided to make the school a showcase for educational uses of technology. Finding little political support for making South Creek a technology magnet school, he took the risk of allocating significant funds to build a technology-rich school that would serve a primarily minority, low-SES student population. He hired South Creek's new principal a year ahead of the school's reopening and charged her with developing a faculty for a "state-of-the art" middle school. He stressed effective-schools principles, such as high standards for all students, monitoring and feedback, a safe environment, and site leadership, as well as the use of technology.

Reform Features. Linchpins of South Creek's approach are the organization of teachers and students into co-located teams, 90-minute block scheduling with extensive access to technology, and site-based management.

For most of their day, students stay within an area, going from class to class and working with the teachers within a particular team. Each team typically includes one teacher each in mathematics, social studies, language arts, and science.

The 90-minute teaching blocks per day permit full lesson cycles, from teacher explanation and modeling to practice of applications in class, where the teacher can provide support and diagnosis. Students receive 90 minutes each in mathematics and language arts every day. The block

South Creek Middle School (Concluded)

scheduling also contributes to teaming and teacher professionalization. Each teacher has 90 minutes a day for planning and preparation; on alternate days, these periods are used for team meetings. The scheduling allows the team to collaborate and individuals to master new skills or develop new units.

Major school decisions are made through consultation between the principal and an Operations Committee of eight elected teachers who meet once a week.

In the team area offices, an impressive array of technology supports teachers' efforts. Electronic mail facilitates communications among teachers and with the administration. *Class Master* software reduces the time needed to report attendance and record grades.

Teachers promote students' higher-level thinking by planning multifaceted activities that involve the use of technology. For example, in a seventh-grade math project on the use of spreadsheets, students estimated and collected measurements of body dimensions, entered data on spreadsheets, explored ways of representing the data graphically, and wrote a brief narrative at the word processor describing their approach and results.

In industrial technology classes, students worked in collaborative groups to design and produce a variety of products. Projects as long as a semester are interdisciplinary, involving reading (e.g., reviewing manuals, conducting market research), writing (e.g., technical reports and project descriptions), math (e.g., drafting and scaling product designs, calculating costs of materials), science (e.g., studying physics as it relates to the performance of materials), and design (e.g., computer-assisted drafting and design). Students formed companies and produced products for sale. They are encouraged to access outside information via the state education network or from CD-ROM.

Technology Supports. South Creek has its own technology committee and technology manager. Technology topics are often discussed in faculty meetings, and the technology manager hosts a "promising practices" series. A good portion of district-provided in-service time is devoted to refining skills in teaching with technology. The district has provided leadership and technical support for the technology innovations but left decisions about details to the local site.

Outcomes. In the year after it opened, South Creek's students were second in their district in mastery of grade 6 mathematics objectives, despite the fact that the school is sixth lowest out of seven middle schools in SES. On the state's assessment system, South Creek students consistently score well above their peers at other schools serving students from similar SES and ethnic backgrounds. A portfolio of school accomplishments is maintained, and there have also been student portfolio projects in many of the classes. The annual teacher survey of effective-schools correlates shows high teacher satisfaction with South Creek. The attendance rate is high (97%), and dropout and retention-in-grade rates are low.

TeacherNet

Context. TeacherNet is a not-for-profit collaborative partnership among school districts, university systems, business, and community agencies that uses technology as a vehicle for educational reform. It encompasses a 10-county area in two neighboring states. The K-12 education partners encompass 54 school districts, 462 schools (serving 250,000 students), and 18,000 teachers. The districts and schools that participate in TeacherNet vary greatly with respect to wealth, size, and demographics, and a more equitable sharing of resources was one of the motivations for starting the association. The largest of the 54 districts serves 35,000 students; the smallest serves 127 students. The 10-county metroplex is relatively high tech—one in every four homes has a computer. TeacherNet is “located” in each classroom, teacher’s office, administrator’s office, partner’s office, and home that is connected to the TeacherNet Telecommunications System (TTS), which provides participating members with access to electronic communications, a curriculum library, news and information, reference/research sources, and access to the Internet. The Omni Educational Institute (OEI), which organized the founding of TeacherNet, serves as its physical hub. Under the guise of a small storefront in the quiet business section of a small city, OEI is actually a hotbed of technology-inspired educational reform.

Reform History. OEI had been providing educational technical assistance, consultation, and training in the metropolitan area for over 15 years. It was also well aware that the various reform efforts under way locally were underfunded, uninformed, and uncoordinated. In 1987, OEI took the lead in convening a meeting of school superintendents described as “risk takers”, because, historically, the school districts in the area had not worked well together and most of the superintendents did not know one another. The original Board of Governors (14 superintendents and the OEI director) created bylaws that regulated the process of putting resources into TeacherNet and accessing TeacherNet’s pool of resources. Many lawyers were involved because of co-ownership issues. It took 18 months for their “cooperative management team” to set up the processes for contributing and using resources. OEI was charged with managing the TeacherNet budget and putting a cooperative technology model in place. OEI decided that accessing technology via a network was the best direction to go. OEI recommended Delphi as the common carrier because it would charge a flat rate and could handle the diversity of computer systems across the 54 districts and 462 schools.

In 1991, representatives from business partners joined the TeacherNet Association in strategic planning and helped to formulate a set of reform goals, including relevant, technology-enhanced curricula in health, science, and mathematics. The group produced a 5-year plan for developing the eight primary applications of the TeacherNet Telecommunications System (TTS): (1) Communications (e-mail for teachers), (2) Curriculum Library, (3) Information News, (4) Reference/Research, (5) Quincentenary (information related to the 500th anniversary of Columbus’s first voyage to the New World), (6) TeacherNet Services, (7) Support Materials, and (8) User Guide to TeacherNet.

TeacherNet’s eight professional staff, including a retired superintendent and a teacher on leave, bring a diverse range of skills to the agency’s services. OEI’s executive director estimated that approximately 90% of OEI’s efforts are currently focused on managing TeacherNet.

TeacherNet (Concluded)

The other 10% of their efforts are dedicated to training teachers; program design; grant writing; program marketing; program coordination; and forming liaisons with universities, businesses, and the community.

Reform Features. TeacherNet is used by students primarily as a way to explore databases and access information electronically. For example, the electronic research course developed at one TeacherNet high school stresses independent use of technologies ranging from library automation systems to CD-ROM applications and services and resources offered through the Internet. After exposure to a variety of electronic research tools such as DIALOG searches and Veronica searches with Gopher on the Internet, students practiced using the tools to collect, analyze, and synthesize information pertaining to thematic projects in the areas of student rights, habitats, pollution, and AIDS research. One group of students searched for Supreme Court decisions regarding student rights. After conducting their electronic search and reviewing the case materials, they wrote and presented position papers and then discussed them in roundtable sessions. Another project involved designing a plan for colonizing a planetary object of the student's choice. Students used the Internet to search for information on their planet and download graphics, such as images of Jupiter's moons. Using all these data, they wrote reports about how they would colonize the planet. Students in a social studies class used TeacherNet to access the CIA fact book—rather than relying on textbooks—to collect up-to-date information for class assignments. Students had access to DIALOG for researching databases from over 100 newspapers, 200 journals, industry publications, Associated Press, and United Press International.

Students felt that computer searches were much easier and more comprehensive and yielded more timely information than library searches, but the students also complained that it took too long to download files and that the school did not have enough modems to accommodate their need to access the system.

Technology Supports. OEI has offered a variety of TeacherNet classes, but some teachers have complained that the course schedule demands too much of their evening or weekend time. To get around this, some of the schools have arranged release time at the school site. OEI also provides a help line so that teachers can call in any type of problem or question. Access to technology (lack of phone lines and modems) remains the largest barrier to widespread use of TeacherNet at most schools.

Outcomes. Given the scope of TeacherNet's membership, objective comparative data are not available. Students participating in our focus groups indicated that they were more motivated to complete a research project if they could use the Internet instead of the library. Students also stressed the value of computer expertise for their futures. Teachers reported that using TeacherNet changed their instructional strategies from teacher-directed to student-directed approaches.

5. IMPLEMENTATION CHALLENGES AND STRATEGIES

The vision for technology-supported reform-oriented classrooms is one in which student groups work on long-term, multidisciplinary projects involving challenging content that is interesting and important to them with the support of technology tools for collecting, analyzing, displaying, and communicating information. Making this vision a reality poses many challenges, which will be discussed in this chapter along with descriptions of the strategies that various case study sites used to try to meet them. We will begin with two challenges that are central to making an innovation take hold at the school level—giving students adequate access to technology and getting a majority of teachers involved in project-based instruction and the incorporation of technology tools.

Providing Adequate Technology Access

Technology cannot become a meaningful support for students' work if they have access to it for only a few minutes a week. The kind of technology-supported project-based instruction we have described requires a high level of access to the sorts of technology tools that researchers and other professionals use on a daily basis to support their work. For example, most schools reported word processing as one of the most prevalent uses of the computer across grade levels and subject areas. However, in many cases, students were doing very little initial composition at computers. Rather, they were entering drafts that had initially been composed with pencil and paper and using the computer as an editing and publishing tool. Although for some students, the lack of keyboarding skill interfered with composing at the computer, the lack of adequate access to computers appeared to be a larger factor, particularly at sites where computers were located in separate laboratories or where there were few computers within the classroom.

Data from national surveys suggest that although American schools have more microcomputers than those of any other country, the level of access is still insufficient to fulfill technology's educational potential.[3] American students report using computers an average of 40 minutes a week (Becker, 1994). Schools are faced with the reality of a limited budget for equipment and software (and an even more limited inventory of the most powerful equipment) and must make hard choices about how to get the most out of what they have.

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3. Although the discussion in this section is framed with reference to computers, the same issues and strategies are relevant to other technologies, notably telecommunications access.

> *A lot of teachers wanted a lab, but we have 800 kids and they only get to the library once a week, so how could they possibly share a lab? We never have room for this* [a computer lab] *so we haven't had to face that issue. ... I wonder if a lab would mean that they would really learn it? But then there is the issue of, it's just a lab, it isn't integrated. You hate to pull computers out of rooms where they aren't being used, but should those who are using them* [have more computers]*?*
> —Elementary school project coordinator

One of the major decisions that schools embarking on a technology implementation must make is whether to group the computers in separate laboratories, which allow a whole classroom of students to work individually on computers, or whether to disperse them among the regular classrooms. A wide range of strategies for allocating computers were observed. Distribution among the regular classrooms gets the technology to the place where the teachers and the students are, but if the school does not have enough technology to provide a critical mass within classrooms, little benefit is likely to result. In particular, a *uniform distribution formula* that puts one or two computers into each classroom appears ineffective. With a class of 30 or more students, a small number of computers do not provide individual students or small groups with enough computer time to have a positive impact. We would not argue that schools must have a computer for every student (many activities are not computer based), but it does seem that something on the order of 6 to 8 computers (enough for a quarter of the students working individually or half of the class working in pairs) is necessary to provide an environment where access problems are not an impediment. This level of equipping regular classrooms is much higher than the computer-to-student ratio of the typical American school; even so, it provides students with adequate access only if the teacher is skilled at orchestrating activities in such a way that students learn how to work jointly on computers and that both technology-based and technology-independent activities proceed concurrently.

For schools that do not have the equipment inventory to give this many computers to all classes, one option is *distribution to classes in special projects*. This approach provides some classes with enough technology to do some good and increases the likelihood that the teachers receiving the technology will have clear ideas about what they want to do with it. Even without special projects, schools may find advantages in *incremental roll-out* of technology. Often this is done on a grade-by-grade basis, but it could also be done on the basis of teacher interest or subject matter. One of our site principals suggested beginning with kindergarten and first grades and then adding technology to succeeding grades each year. In this way, students in the first kindergarten class would have technology throughout their school career, and the upper grades would end up with the newest and most powerful equipment. The incremental approach spreads the cost not only of hardware and software but also of teacher training. The experiences of the pioneering classrooms can help other teachers implement technology more effectively.

Another option for schools that cannot afford to place 6 to 8 computers in all regular classrooms is setting up a *computer laboratory*. This setup has appeal in cases where most of the regular classroom teachers lack technology expertise or interest; a computer coordinator can be responsible for keeping the centralized computer resources up and running and for designing instructional programs involving the computers. The potential disadvantage, particularly when students work in the lab on activities designed by a computer coordinator rather than on regular classroom assignments, is that the technology lessons in the computer lab tend to be "inert"; if students do not use technology tools in accomplishing their work for the regular classroom, the power of technology will not be harnessed in the service of the core curriculum. In addition, when technology-based activities are planned and executed by someone other than the regular classroom teacher, regular teachers find the activities in the computer lab easy to ignore, and they feel no pressure to learn how to use technology within their own teaching. Several of the sites in our study began with a computer lab approach but later distributed the computers into classrooms to achieve greater integration with the curriculum.

In the past, computer laboratories were associated with classes teaching computer literacy, programming, or other computer topics at the secondary level and with integrated learning systems (ILS) providing individual students with drill and practice on basic skills at the elementary school level. This situation is changing. More and more schools are finding a place for general-purpose computer laboratories where students can go to work on projects for their other classes. In the computer laboratory at the Maynard Computer Mini-School, for example, students used technology in many tool-like ways—e.g., to obtain information over the Internet, to send electronic mail, and to do word processing of reports—for assignments and projects connected with their regular classes. What made this arrangement work was that the computer lab was located right next to the regular classrooms and that students had extensive access to it through the combination of the mini-school teachers' policy of allowing students to leave their regular classes to use the lab as well as the fact that the lab was open before and after school and during lunch.

Several sites distributed their computers across both labs and classrooms, where they were used in different ways for different purposes. At South Creek Middle School, the School of the Future, and East City High School, a series of computer labs were used for whole-class activities in particular subject or project areas (e.g., writing, science, research, multimedia). Smaller numbers of classroom computers (one to five per classroom, depending on the site) were used by the teachers for material preparation and communication, as well as by the students for individual or small-group work. This arrangement seemed to work particularly well for the middle and secondary school levels, where the curriculum tends to be more specialized.

An alternative to the centralized computer lab that was used in several case study schools was the *mobile computer lab*. Both John Wesley and Bay Vista put computers (in fact, their most powerful computers) on carts and had them rolled from room to room. Computers have become adequately rugged and portable to permit this kind of use, and both schools felt that the strategy, although perhaps not ideal, made higher levels of access available to students and heightened utilization rates for their equipment. Coordination issues come into play, of course, as teachers need to schedule time with the mobile computer lab and someone (usually students) needs to move the equipment from place to place. Hard feelings can develop if some teachers feel that others are monopolizing the equipment, but in general these issues can be worked out as a matter of school policy.

Finally, some schools have not aimed for dispersing technology across all classrooms but rather have chosen to institute a "*technology mini-school*" with a high level of technology access. Both the Maynard School and East City High School cases were examples of this approach. Advantages lie in the very high level of technology access that can be provided for mini-school students and in the option to carefully select teachers who are enthusiastic about incorporating technology into their teaching practice. Disadvantages lie in the potential for the mini-school students and staff to become isolated from the remainder of the school and for technology to become something that divides rather than unifies the school. Exhibit 1 provides some profiles of different approaches to addressing the technology allocation problem. Table 2 summarizes the advantages and disadvantages for these allocation approaches.

Even when students are given a high level of access to computers at school, the fact that most students cannot continue their computer-supported activities outside of school poses limitations on the kind of work that they are able to do. This problem is particularly apparent for schools serving large numbers of students from homes with poverty-level incomes. As one teacher pointed out, not only technology's cost but also its portability is at issue:

> *If we had enough computers and could use them every day, they could use them in place of their notebooks. But then you have the issue of home. They don't have computers in their homes...and a lot of their composing and revision is done at home, so there's a whole other issue. It's impractical the way the technology is because it seems to be just kind of hanging. It's neither one or the other. We're using notebooks, which seem archaic and obsolete in a lot of ways, but they're with them all the time. They're with them on subways or on a trip or whatever. That to me is first priority —the writing of it, not the technology. The technology is only a tool, and right now it's not a good enough tool.* —Elementary school teacher

Exhibit 1

Examples of Strategies for Allocating Equipment

Distributing a Large Inventory of Computers within a New Technology Middle School

When planning for the reopening of this former junior high as a technology middle school, the district made a major investment in over 400 networked Macintosh LC computers for South Creek Middle School. Each regular classroom was assigned 5 or 6 computers. In addition, several labs of about 30 computers and a library media center were included in the plan. Each classroom has a monitor and VCR. Most of the technology ($2.2 million worth) was purchased for the school's opening. Upgrades and additional software are added every year, however, and a recent investment in a T-1 line brought increased telecommunications capabilities.

Creating a "Mobile Laboratory" for a Small Number of Computers

Bay Vista Elementary School classrooms share the school's higher-end computers through a mobile lab arrangement. Seventeen Macintosh computers are kept on desks with wheels. One teacher maintains the mobile lab schedule, and all teachers schedule these computers into their classrooms for technology-based activities as needed. Each term, a team of four students is assigned to each computer to ensure that the computer is transported securely from class to class. Students consider this assignment an honor and a serious responsibility. Because most of the classrooms in this school are in separate "portable" buildings, one student is also assigned as the "step monitor" to guide the teams of students moving the computers down the steps. At the count of three, the students lift the desk and carry the computer safely to ground level and roll it away to the next classroom. This is an amazing sight to see, especially on rainy days when students cover the computers with large plastic tarps before exiting the building!

In addition to the mobile lab, classrooms have a few less-powerful computers on permanent assignment and access to a project room with 14 networked PCs.

Centralizing Equipment in a School-within-a-School

Eight classrooms are part of Maynard's Computer Mini-School. The mini-school's computer inventory is concentrated in two computer labs. The original computer lab is equipped with 25 to 30 computers, linked on a local area network (LAN) to a Gateway 2000 file server providing access to a full range of tool applications (e.g., word processor, database, spreadsheet) and a wide array of instructional software. Each student has a folder on the file server containing his/her individual work. In addition, each student has his/her own e-mail account. Their WAN connection features a high-speed data line and a client-server model of access that enables students to connect with resources on the Internet as readily and as easily as they are able to access local applications. Front-end user interfaces (Gopher, Mosaic) facilitate the location and use of available resources.

Exhibit 1 (concluded)

The lab is open from 8 a.m. to 6 p.m. daily. In addition to 16 scheduled classes each week (two 1-hour sessions per classroom), the lab is open to students during school hours between scheduled classes and through lunch, as well as before and after school. Students make heavy use of these flexible periods of access for writing, research, and other project-related work, as well as for self-selected and recreational activities.

Adjacent to this computer lab, an Integrated Learning System (ILS) was added in 1993. The ILS lab is used for non-mini-school classes but is available to mini-school as well as other students before and after school and during lunch. The ILS network is linked to the network in the main computer lab, making it possible for up to 80 students to use the network's resources, including the Internet link, simultaneously.

All but one of the eight mini-school classrooms are located on the same floor as the computer labs. This physical proximity supports extensive use of the computer facilities, and teachers commonly send individual students or small groups from their classrooms to use the lab facilities for their regular classroom work. Although each of the regular classrooms is equipped with one or two computers, these machines are rarely used because these are older models (mostly Apple IIe's) and students have such ready access to the more sophisticated equipment within the lab.

Transitioning from a Lab to Distribution to Regular Classrooms

Technology use at Nathaniel Elementary began with the installation of an Apple IIe lab. A computer lab teacher was hired, and students were brought to the lab once a week during their teachers' 50-minute prep periods. During these sessions, they engaged in instructional games and word processing. As time went on, the lab instructor became increasingly frustrated because this arrangement did not provide a high enough level of computer access to allow for technology-supported activities that were integrated with the curriculum in meaningful ways. At one point, she attempted to introduce LOGO programming, but found that students would often forget key concepts and commands from one week to the next.

The decision was eventually made to separate the lab teacher position from the constraints of the prep period, allowing for greater flexibility in how the lab was run. The change enabled the scheduling of 6-week mini-courses that met three times per week (rotating between classes). Because the lab was no longer used to cover prep time, teachers were able to stay in the lab with their students, providing additional instructional support and learning the technology in the process. The school made the transition to another level of technology use several years after the lab was installed, upon receiving funding for incorporating technology into a large number of classrooms. The lab continued to be used for special activities, but the bulk of technology-supported learning was transferred to regular classrooms. With the transition from lab to classroom, the computer instructor notes that her role became increasingly devoted to technical troubleshooting, demonstration, and curriculum support. She further observes that students came to view computers in a new way, as "tools they used for a variety of purposes" rather than in terms of instructional games.

Table 2
STRATEGIES FOR ALLOCATING TECHNOLOGY

Strategy	Advantages	Disadvantages
Computer laboratory	Enables a whole class to use technology simultaneously A single technology coordinator can plan activities and keep technology running	Regular teachers may be disengaged from technology use Less likely to affect core program
Distribution formula	Equipment available in regular classrooms, permitting better integration with core program Perceived equity across classes	Requires large equipment inventory to permit reasonable number of students to access in parallel Equipment likely to receive little use in some classrooms All teachers require training and technical support
Incremental roll-out	Lower initial funding requirement Can train teachers incrementally and have them help train others	Potential for impatience on the part of teachers in latter phases Incompatibility between equipment purchased at different phases
Distribution to classes in special projects	Technology used more efficiently and effectively when placed in classrooms where there is a plan and support for its use	Potential perception of favoritism Students in some classes may receive little or no technology access
Mobile laboratory	Maximizes use of limited technology inventory Perceived fairness	Logistics requirements for scheduling and transporting equipment Teachers use less than if technology stationed in their classroom
Technology mini-school	Allows high level of access for subset of students Can focus training on subset of highly motivated teachers	Teachers and students not in mini-school receive few advantages Tendency toward isolation

Equalizing Technology Access

A corollary to the challenge of providing adequate access to technology generally is the concern with making sure that different kinds of students get equal access. Data from national surveys suggest that students from low-income homes and ethnic minorities are less likely than their more affluent peers to have computers in their homes (Becker and Sterling, 1987). Although the differences are smaller than those for ethnicity and socioeconomic status, there is also a gender difference in technology access to computers, with boys having more home access than girls (Chen, 1986; Sutton, 1991). Even when students from low-income homes or girls are in classrooms with technology, there are many anecdotal reports of their having less time with the technology than do boys from more affluent homes (Sutton, 1991). Some reports focus on the more assertive behavior of boys in "claiming" computer time or control of the mouse; others describe girls and low-SES students opting out of activities in which they do not expect to excel.

> *I came from a school where most of the families could afford a computer and the kids that didn't...had the tendency to withdraw and put their heads down and not really want to be into anything technology-based.* —Middle school mathematics teacher

Our case study sites were quite sensitive to issues of equal access. In fact, the need for schools to be active in giving high-quality technology experiences to students who would have less access to technology in their homes was a motivating factor in setting up a number of the programs. (See Chapter 7.) In some cases, classes instituted explicit policies to ensure that all students had equal access to technology that was in limited supply. For example, in the Nathaniel classes participating in the CSILE project, each child was scheduled for a minimum of *30 minutes a day* at the computer. At the Maynard Computer Mini-School, each student had a scheduled 2 hours a week in the computer lab (with his or her regular class), plus the opportunity to come in before or after school, during lunch, or at other times with the teacher's permission. About half of the students took advantage of this opportunity for additional time working with computers, and there were no apparent differences in the participation rates of boys and girls.

Given the predominantly low-income, ethnic minority character of the schools' student populations, the case studies offered few opportunities to assess whether or not there was differential participation rates along SES lines. Observations in other classrooms would suggest that schools need to be sensitive to this possibility. In addition to developing policies to equalize in-school technology access time, schools need to consider the need for developing norms for cooperative technology work that ensure that all children get opportunities to take the lead. In several classrooms, students working in pairs at computers regulated their own sharing of roles, trading off control of the keyboard at regular intervals. Several other schools attempted to mitigate the differences in technology background stemming from differential experience with computers in the home by instituting take-home computer programs. One such program is described in Exhibit 2.

Exhibit 2
Example of a Student Take-Home Computer Program

According to estimates given by both the principal and the technology coordinator, fewer than 1% of the students enrolled at Nathaniel Elementary School have access to computers at home. To enable their students to compete with students from more affluent homes in future education and work settings, Nathaniel staff felt that they needed to try to provide these students with in-home as well as at-school technology experience. Nathaniel Elementary decided to purchase 78 Macintosh Classics for use in a special parent/student take-home computer program. The computers were purchased with funds from a district-sponsored restructuring grant (the district initially recommended the purchase of ILS software for the school's existing Apple IIe lab; but the school had other ideas, which the district gave them the flexibility to implement).

The take-home program provides families with computers on a 4-week loan basis. Participation in the program is self-selected. Parents are required to attend a 6-hour training session covering computer basics (how to turn the computer on and off, how to load programs) before taking the computers home. The school's technology coordinator reports that the program has been highly successful, especially for students, who use the on-loan computers for a wide range of personal and school-related activities.

As stated above, we observed roughly equal participation of girls and boys at most of our case study sites (the exception being the School of the Future, which had a low female enrollment, and the Electronic Research class at one of the TeacherNet high schools we visited). This finding stands in contrast to the lower participation rate for girls in many classes observed by others (Mark, 1992). Our observations suggest that when technology becomes thoroughly integrated into a school, such that there are many different technology uses and many technology-using models available, girls will find technology-based activities as motivating as boys do. They may select somewhat different technology activities (a lower interest in computer games and a higher interest in composing at the computer were cited by some informants), but their overall level of use will be comparable. When technology is a part of all kinds of subjects and of every class, when it is used in social studies and fine arts and not just in a specific computer class or a special math class, students are going to see a good many female technology-using models, and this is likely to have an impact.

> *One of my bugaboos has been that computers have been sexually biased, more of a male thing. I think because I'm a female and I'm the one that is being a presenter and I'm the one that knows* [about technology], *that* [the gender stereotype] *does not exist in my class. I think that it breaks out even. The boys do not take over because the girls can do just as much.* —Progressive School teacher

Thus, our observations are consistent with research suggesting that collaborative uses of technology increase its appeal to girls (Herman, 1985) and that gender differences in technology interest are not present when boys and girls have equal levels of experience with computers. (Chen, 1986).

Involving a Majority of Teachers

Placing technology in classrooms does not ensure that it will get used appropriately, or even that it will get used at all. Many of us have visited classrooms with one or two computers in the back covered with a plastic cover that is rarely removed. The reformer's vision of project-centered classrooms with students using technology tools makes extensive demands on teachers. Teachers are expected to orchestrate a classroom in which students pursue different questions, work at different speeds, use different materials, and work in flexible groups. Students will be working with original data sources, often pushing beyond the limits of the teacher's knowledge, and learning to work together to produce products that demonstrate what they have learned. All of this must be carefully planned and supported by a teacher in such a way that the students take ownership of their projects and feel responsible for their own learning, while at the same time ensuring that the essential content in local, state, or national curriculum standards in multiple areas are met and that students will perform well on whatever high-stakes assessments are to be given. There is no doubt that the reform agenda calls for fundamental changes in teaching practices on the part of most teachers. In some ways, the introduction of technology only adds another level of complication to what is already a daunting task. How does a school get all or almost all of its teachers on board, particularly when many of those teachers have little experience with technology?

Our case studies provide some interesting insights. In most of the schools we visited, teachers were at different stages in their use of technology. In a few cases, the range of familiarity and expertise went from one end of the continuum to the other: some teachers were still reticent to use computers at all, others were at the "let's try it and see if it works" stage, and some had acquired a sophisticated level of skill and were incorporating technology throughout their teaching practice. Some teachers encouraged their students to use computers to accomplish tasks, but they themselves did not engage in any computer-supported activities. Several teachers reported that the primary reasons for their nonuse of computers included the fear of damaging the equipment, the lack of time for training and exploration, and the inability to see a meaningful match with the curriculum. The issue of how to get teachers on board with technology was a topic of interest and concern to many of the administrators and technology coordinators we spoke with. Whether schools were built from the ground up as technology-supported sites or were attempting to incorporate technology into an already established program, the integration of technology has been a gradual process. The few schools in which technology implementation appeared to be very widespread and well integrated throughout the curriculum shared a number of characteristics, including a large enough number of computers to allow for frequent access, strong leadership, a collaborative environment and shared instructional goals, extensive opportunities for teachers to learn and work with the technology, and on-site technical support.

In general, program designers shared the perception that teachers should not and cannot be pushed into using technology.

> *It is something that I have wanted immediately. ...I have had to understand that you can't save everybody and you can't push people from the point that they are at. You can only make suggestions and show them things that they might be able to integrate into their classrooms, and if the interest and excitement is there, they pick up on it. Not everybody is going to be able to use* [the computers] *right away.* —School technology coordinator

Rather than forcing teachers to use technology, project leaders recognized that teachers would come along at their own speeds. Most schools will have some "early adopters" who are interested in technology and eager to learn about it and try it out with their students. These teachers can become a core group, able to sustain their interest despite the inevitable glitches and setbacks of the early stages of a technology project. In our case study projects, such early adopters showed themselves not only willing to spend their own time to learn about technology but also willing to spend time on chores such as learning to repair computers and keep a network operating, scheduling equipment rotations, and advising their fellow teachers on technology options.

If technology-supported educational reform is to really change a school and affect students deeply, however, it needs to spread beyond a handful of teachers. The experiences of our case study sites suggest the *importance of getting broad agreement on a school-level vision of what the school wants to become*. As in the case of the John Wesley and Progressive School sites, that original vision may not include technology. A consistent set of instructional goals and practices is more important. If technology can support these goals (and we believe it can be an important support, particularly for project-based learning activities), teachers then have a motivation for learning how to use technology and to incorporate it into their teaching practices.

The experiences of our case study sites suggest that, in fact, the move to project-based work, without relying on lecture methods or following a textbook, is a more fundamental and difficult shift than the introduction of technology. Teachers who have learned how to design challenging activities in which students work on cooperative projects and who are able to manage multiple student groups working on different phases of their project activity find that the introduction of technology goes relatively smoothly. Since students are not expected to all be working on the same thing at the same time, the class does not need one computer for every student or student pair. Moreover, students who are used to working together find it very natural to consult with each other on their technology-related problems. Particularly in the upper grade levels, teachers who have become accustomed to playing the role of coach rather than that of all-knowing lecturer and demonstrator find that they can rely on students to help set up equipment and troubleshoot technical difficulties. A number of teachers reported that they became willing to take on technology after witnessing the active role that students were able to take in teaching both themselves and one another.

One strategy for getting teachers involved with technology that has been used in many places is to *give teachers computers for their personal use*. States and private donors have set up such programs, typically with certain requirements, such as attending a class on how to use the technology. These programs give teachers a better idea of what can be done with the equipment and get them accustomed to using the equipment as a tool for their own productivity. With their own personal experience of the ways in which technology can support their productivity, teachers are more likely to see ways in which similar uses could support the projects they want their students to do. In addition, as one teacher pointed out in her interview, take-home computer programs for teachers have important motivational value:

> *If they cannot afford to give their teachers a computer to work with at home, why should the teachers make that commitment* [to learn to use technology]*? I think that was the one piece that made the teachers feel real professional. It made every teacher feel, "I am valued and I will buy into this. I cannot sit here with this computer on my desk at home and not do something about it. I can play with it all weekend."* —Elementary school teacher

Quite a few of our case study sites had programs that gave teachers computers for home use (usually on a loan basis). These programs were successful in increasing the numbers of technology-using teachers. Exhibit 3 describes one of these programs and the impact it had on teachers and the technology implementation effort.

Exhibit 3

Strategies for Involving Teachers

A Teacher Take-Home Computer Program

At John Wesley, a take-home Duo Dock program was implemented in 1993-94 with great success. Although the school's restructuring efforts had included the use of technology since 1988, only a portion of the school's teachers had really become enthusiastic users of technology in their classrooms. Many teachers, particularly in the primary grades, were reluctant to become involved. In January of 1994, teachers were given the opportunity to obtain a Macintosh Duo (a notebook computer) for their own use if they agreed to take a day-long introductory training and to use the machine in their classrooms as well. (The computer becomes the personal property of the teacher after 5 years if he or she is still at John Wesley.) Initially, all but one teacher signed up for the program, and the last teacher decided to participate after coming in one day to "play with" one of the machines. Additional mini-training sessions on technology topics selected by the teachers were offered after school, and technology use in the classroom became more widespread. The part-time technology coordinator estimates that 70% of teachers now use these computers to write narrative reports for parents, and 80% of teachers are using computers for classroom instruction. Although the level of use still varies, most classes are providing computer-based activities every week.

An In-House Proposal Process

When news of an externally funded technology project comes to Nathaniel Elementary, an announcement is made to the entire school faculty inviting any who are interested to attend an after-school information session. Nathaniel is a large urban school, and, in most cases, these projects have been limited to a handful of classrooms. Once the information regarding the project is made available to the staff, teachers who wish to participate are asked to submit a proposal outlining their goals and describing the ways in which they feel their classrooms would benefit from participation. The proposals are then reviewed by an in-house committee that consists of the principal, the technology coordinator, and several teachers. This process has been used to select classrooms for participation in several different technology-supported projects, such as CSILE and Project GALAXY.

Another strategy for spreading the use of technology is to *provide teachers with remuneration and recognition for designing good instructional uses* of technology. Some districts, for example, offer "mini-grant" competitions through which teachers can obtain resources for trying out innovative instructional uses of technology in their classrooms. One of our case study sites benefited from a program offered by Apple Computer; during school year breaks, the company paid the school's teachers as consultants to develop instructional uses of software running on Apple computers. Teachers received extensive technical support and training during these consulting periods, which in turn enhanced their ability to integrate technology into their teaching.

Finally, adoption of *goals for technology skills* was another way in which pressure was exerted on teachers to incorporate technology into what they were doing. One of our middle school sites was located in a state that had specific technology competencies that students are supposed to acquire by the end of eighth grade. An elementary case study site recently began work on a continuum of technology competencies for different developmental levels that will become part of the schoolwide set of instructional goals. The project coordinator expects the articulation and assessments of these competencies to influence those teachers who have been slow to implement technology.

A strategy that our case study sites said they did not use is emphasizing prior technology skills in hiring new teachers. Even the two new schools designed to be technology demonstration schools did not emphasize technology skills in their staff selection. Administrators emphasized that good teaching skills and the ability to work well with a diverse population of students were more important. What they did seek in selecting teachers, however, was an interest in trying out new things and a willingness to learn about technology.

The extent to which technology was well integrated into regular classrooms across our study sites was related to use of these strategies. Those sites that employed more strategies (i.e., that had a well-planned effort to disseminate technology activities) succeeded in getting a larger proportion of their teaching staff involved. Table 3 summarizes the use of these strategies across our case study sites.

Providing Technical Support for Technology Use and Maintenance

Even after teachers' initial fear of getting involved with technology has been overcome, serious challenges remain in terms of providing enough technical support that teachers will not be discouraged by equipment failures or software behavior they do not understand.

> *It's like putting gas in the car; you put it in and you want it to run and you don't ever look under the hood. I think it's the same with computers...we need someone...who, when computers break down, can be a troubleshooter.* — Elementary school project coordinator

There appears to be general agreement among observers that, at least in the foreseeable future, schools that are attempting to implement technology on a wide scale need to have on-site technical assistance. Although some sites have attempted to make do with help from a knowledgeable teacher volunteer or with part-time services from a district technology coordinator, such arrangements are often unsatisfactory. Like all of us, teachers trying to use technology in their

Table 3

STRATEGIES FOR INVOLVING A MAJORITY OF TEACHERS

Strategy	BVE	ECHS	JWE	MS	NE	PS	SCM	SOTF	TNet
Create cadre of innovators to start snowball	✔				✔	✔			✔
Seek agreement on school vision and technology's role within it	✔	✔	✔			✔	✔		✔
Give teachers computers for personal use		✔	✔		✔	✔		✔	
Provide remuneration and recognition for instructional uses of technology	✔	✔				✔	✔		
Adopt goals for technology skills			✔				✔		✔
Provide supported time for learning to use technology and designing instructional applications		✔				✔	✔		
Provide easily accessible technical support for technology use				✔	✔	✔	✔	✔	✔

classrooms want technical help *on demand*. Controlling a classroom full of students in the midst of some activity that requires technology when the system goes down requires flexibility and skill. If technical problems arise frequently and teachers have to wait hours, days, or weeks to get them resolved, they will abandon their efforts to incorporate technology. Exhibit 4 describes how the availability of technical assistance affected teachers' willingness to implement a specific project.

Quite a bit of technical support is needed in schools where all or most teachers are using technology, particularly if new or experimental systems are involved or extensive use is made of computer networks. At least five kinds of technical assistance are necessary:

- Help in planning for technology uses and acquisitions
- Training in how to use new hardware and software
- Demonstrations and advice on how to incorporate technology into instruction
- On-demand help when software problems or hardware failures arise
- Low-level system maintenance.

Exhibit 4

Effects of Varying Levels of Technical Support

The Computer Supported Intentional Learning Environment (CSILE) project at Nathaniel Elementary has gone through several phases of implementation, with varying degrees of technical support. During the first year of the project, participating teachers were flown to a 3-day conference that introduced them to the CSILE model of collaborative knowledge building and brought them together with teachers from around the country who were piloting the program. Teachers were given e-mail accounts linking them with other participating teachers and with the development and support staff. Nathaniel teachers rarely made use of these accounts because the school's modem was located in the computer lab, rather than in their classrooms. Teachers and students began exploring CSILE with limited technical support; however, its use within the classroom was limited by their initial lack of expertise, the need for curriculum support, and problems associated with early versions of the software (e.g., software bugs, frequent upgrades).

During the second year of the project, a major reduction in technical support due to funding cutbacks brought CSILE to a standstill. As one teacher describes it, "No one within the district or the school knew CSILE well enough to offer support, so things fell apart." Major changes came about in the project's third year, when additional research funds provided a high level of technical and curricular support and a much stronger program implementation. CSILE's founding researchers conducted a series of visitations. Two of their graduate students spent 2 days each week at the school providing direct technical assistance and facilitating the integration of CSILE into the curriculum. In addition to their individual classroom support, the graduate assistants met with the participating teachers as a group twice a month. During the meetings, teachers discussed their curricular goals, and possible matches with CSILE were suggested. According to the teachers, this level of support has been instrumental in their ability to integrate CSILE more meaningfully into their curriculum:

> *Last year we didn't really use it because of all the upgrades and no support. For example, if you turn it on and it doesn't work, I can't figure it out and we don't use it. The other big shift was that when we first learned CSILE, I was trying to have my curriculum fit in with CSILE...creating units so that it would be compatible with CSILE, which now I think is backwards. Now what I want is for the technology to support what we are doing in the classroom. And that was a realization that I had this year when we were discussing CSILE with the creators, and that idea came out. We are the "experts" on what we're doing in the classroom, so why don't we have a discussion about the archaeology project; let the CSILE people listen in...they're the experts on CSILE and how the technology operates. After hearing what we're doing, then they can give us suggestions for how we can integrate CSILE into what we're doing and how it would enhance what we're doing, which is really how it should be.*

The relative importance of these functions shifts over time. The initial phases of implementation, especially within projects serving as testbeds, are more likely to be riddled with frequent software glitches and system breakdowns, requiring ongoing troubleshooting and on-site technical expertise. As projects mature, there tends to be less need for teacher "hand-holding" to get over initial anxieties and lack of knowledge about how to use functioning equipment, but the need for maintenance increases as hardware ages. Further, there is a continuing need for planning and for figuring out an appropriate way to allocate resources and to make reasonable use of the less-powerful equipment in the school's inventory. Further, as projects mature and wide area network resources for education increase, schools are likely to want to get more active in the use of local and wide area networks, creating requirements for specialized knowledge in these areas.

Our case study sites varied in the level of resources available for on-site technical assistance and in the arrangements that were made. Table 4 provides a summary of the on-site technical assistance available at the sites. Several sites had multiple technical assistance positions, with each resource person focusing on some combination of the functions enumerated above. Some sites had a single technology coordinator who attempted to fill all of these roles. Others had no funding for on-site technical assistance and attempted to make do by developing teacher skills in these areas. At several of the sites, teachers or the technology coordinator took courses to obtain computer maintenance licenses so that they could work on equipment still under warranty.

Table 4

ON-SITE TECHNICAL SUPPORT

Site	Technical Support Personnel
Bay Vista	Volunteered time from several teachers
East City High School	Part-time services of project coordinator
John Wesley	Volunteered time from one teacher
Maynard Computer Mini-School	Full-time computer coordinator
Nathaniel Elementary	Full-time technical coordinator
Progressive School	Full-time technology coordinator; two part-time technical support staff (up to 1993-94)
School of the Future	Part-time technology manager
South Creek Middle School	Full-time technology manager; full-time computer literacy specialist
TeacherNet	Varies by school; network offers helpline staffed 24 hours/day

Several technology coordinators felt that the most important aspect of their role over time was assisting teachers with the integration of technology into the curriculum. One technology coordinator described her role as shifting to that of "technology curriculum resource specialist." This latter role requires much more than technical troubleshooting. It requires ongoing communication (i.e., time to meet and plan together) as technology coordinators collaborate with teachers in identifying appropriate matches between instructional needs and potential uses of technology. This process can lead to exciting new ideas and approaches, as teachers have the opportunity to rethink their instruction in relation to software tools and technology capabilities that they otherwise might not have been aware of. This was certainly true of the collaboration that occurred between the technical consultants and the teachers involved in the CSILE project at Nathaniel Elementary (as profiled in Chapter 9 in Exhibit 12). Teachers at other schools have cited this as one of the most valued or most needed (in cases where this assistance was not provided) supports in the process of technology implementation.

Not all technology coordinators are equally successful at working with teachers, however. Whereas the technology coordinator at one school was cited by teacher after teacher as being instrumental in helping to design and implement technology-using activities, the technology coordinator at another school was mentioned by no one until asked whether such a position existed. The latter coordinator felt isolated within the school and frustrated because several attempted in-service training sessions did not attract participants. Although the overall differences between the two schools in terms of climate were quite large, the different ways in which the technology coordinator's job was perceived seemed important also. The active coordinator appeared to think about his job in relationship to *teachers*. He repeatedly stressed the idea that the teachers were the "stars" and that he was a source of support for what they wanted to do. Nevertheless, he was actively involved in conversations about instructional uses of different kinds of software, as well as in helping teachers develop applications for specific purposes. In a very friendly, deferential manner, he sought out teachers to find out what they would like to do that he could help them with. He expressed sincere admiration for their teaching skills and encouraged them to contact him for assistance after hours as well as during school. We observed him actively working with students in classrooms when new uses of technology were tried out. Despite the fact that he was the only male staff member in this very close-knit school, he was clearly accepted into the social fabric of the school and someone with whom the teachers felt very comfortable working.

The other technology coordinator seemed to have a role defined in relation to the *equipment*. Indeed, when we observed him, he spent his time at the back of the computer labs. His role was perceived more as one of keeping the network running, and teachers did not appear to think about him as a potential resource when considering what they might do with technology within their course curricula.

These examples illustrate the principle that, in addition to technical expertise, technology coordinators need to understand instructional issues and be skilled at working with teachers. Coordinators who show no interest in curriculum or who intimidate teachers with their technical knowledge are rarely effective.

If technology use is to become widespread in regular classrooms, the technology coordinator must view his or her role as passing knowledge on to teachers. In two of our case study schools, technology coordinators were the only ones who knew how to keep the network running. At other sites, technology coordinators made a concerted effort to provide students and teachers with the procedural knowledge that would enable them to achieve a higher level of independence with respect to system operations.

> *Every time there is a problem, I try to show them what the problem was so that the next time it crops up, they'll know what to do on their own.* —Elementary school technology coordinator

Bay Vista Elementary is one school that has managed to do well despite the absence of an in-house technology coordinator. Many of the teachers have become adept at computer maintenance (two have their Apple Level 1 maintenance licenses), and the district has a responsive repair service. Instructional support in technology use is provided in a variety of ways. A project lab is used for hands-on technology demonstrations. Teachers can bring their students to the lab for team-taught sessions or can observe other teachers as they conduct technology-supported lessons. The science coordinator visits classrooms as a mentor teacher, coaching teachers in their use of technology.

It is difficult to interrupt another teacher's work when a need for assistance arises, however, and most schools without a dedicated technical assistance person for all or part of the period of their technology innovation felt the lack.

> *Having a person* [in the technology coordinator position] *is key to the program. A lot of schools in this city have no designated person, except a classroom teacher who has been interested in technology. You really need a person with more expertise who can help the teachers and is free to go to the classrooms when needed.... The classroom teacher doesn't have the time for troubleshooting. They need to feel comfortable with the fact that I will come into the classroom and show the kids.* —Elementary school technology coordinator

Giving Teachers Time to Learn to Use Technology

Providing time for technology-supported education reform is critical. Observers of pioneering efforts in this area argue that changes do not occur overnight. In earlier studies, researchers have concluded that something on the order of *3 to 5 years* is required for teachers to become really adept at incorporating technology into their teaching practice (Sheingold, 1990; Stearns et al., 1991). Innovations can be stymied if policy-makers or the public expect tangible results in the year after the bond issue passes. Indeed, there are cases in which a disgruntled community has dismantled a technology-based innovation because of failure to find near-term positive effects on standardized test scores (Elmer-DeWitt, 1991; Means and Olson, 1994). Schools and districts undertaking technology-supported education reforms need to understand that this is a long-term process (an issue discussed more thoroughly below), and teachers need to be given the supports and the time to become comfortable with technology and to learn to use it effectively.

For new programs, an initial period for administrators and teachers to engage in critical planning, team building, and technology exploration is of critical importance. The principal at South Creek was hired a year in advance of the opening of the school. Teachers attended extensive training and planning sessions during the summer, and collaborative planning time was built into the daily schedule. The school-within-a-school staff at East City High School was brought together for a summer institute to lay the groundwork for the program and to become familiar with the technology. The summer institutes (sponsored by Apple) continued for the first few years of the project. Staffing and class schedules were arranged so that the teachers had afternoons for planning and preparation. During its first 4 years, lead teachers at the School of the Future were given year-round positions, providing large blocks of time during the summer for developing the program and learning the technology.

The kinds of challenging, complex tasks involving technology that we want teachers to pose for students take time to design (or adapt to local curricular goals). The virtue lies not in the technology per se but in the *instructional context* within which it is used. Teachers need time to design such activities, to try them out, and to gain feedback regarding their strengths and weaknesses. They need time to observe each other trying out new kinds of activities and making interesting uses of technology. As noted above, this kind of competence typically takes years to develop. But the years themselves will not be sufficient unless places are made within teacher schedules where these activities can occur.

Exhibit 5 describes some of the innovative ways in which case study sites provided time (and the necessary supports) for teachers to learn about technology and to work on instructional

Exhibit 5

Providing Time, Training, and Technical Support for Instructional Uses of Technology

Innovative Scheduling and Staffing in a Middle School

South Creek Middle School uses an innovative schedule of four 85-minute blocks per day. Teachers provide instruction for three blocks and have the fourth block for personal or group planning (on alternate days). This schedule has provided teachers with much-needed time for mastering new skills (regarding technology and in other areas) and developing curriculum units and creates much greater flexibility, with opportunities to observe each other teach. In addition, a computer literacy teacher and an on-site technology manager (who is in charge of the school's network) demonstrate new technologies and do co-teaching, giving others a chance to observe instructional uses of new technology. Further opportunities for teachers to discuss their technology-based activities are provided at faculty meetings. The technology manager hosts a "promising practices" series at which teachers describe and demonstrate what they are doing with technology. An estimated half of the district-provided in-service days are devoted to refining skills in teaching with technology.

Support from an Outside Research Partner

In introducing large numbers of computers into the Progressive School, Apple was careful to provide a human infrastructure to support the technology implementation. For 6 years, the corporation funded a full-time, on-site technical coordinator, a half-time technical assistant, and a portion of the salary for a telecommunications coordinator. The technical coordinator in particular was credited by many teachers with helping them overcome the many hurdles to their use of technology. Although he helped solve technology problems as they arose, his greater role appeared to be in working with teachers as they thought through their instructional goals and started thinking about the specific uses of particular technologies that would enhance their activities. Teachers described calling the technology coordinator at home in the evenings and on weekends as they were working on class materials. The technology coordinator was a former teacher who took pains to play a supportive role with teachers rather than making them feel self-conscious about what they did not know about technology.

In addition, the corporation paid the teachers as consultants during their breaks to use technology to develop class materials. Teachers developed a number of interesting innovations, such as a *HyperCard* application that combines young students' writing with their drawing and a teacher-provided rewriting into standard English. Paying teachers as consultants not only gave them a financial incentive to participate in these activities but also gave them a tangible demonstration that their own knowledge of instructionally useful activities for various developmental levels was valued.

applications for their classrooms. Most of the schools provided teachers with at least a modest number of extra in-service days and specialized training in technology use. Several sites went much farther, restructuring the school day with provision for time in which teachers could confer, plan, and develop innovative curriculum units. Several other sites, while not providing supported time during the regular school day, received outside funding that compensated teachers for time spent on technology-related activities outside the regular school schedule. In a significant number of our case studies, however, teachers' main source of time for learning about technology and designing technology-based activities was before and after school and on weekends. Clearly, there are limits to the number of teachers who will devote this kind of time without compensation and to the amount of time that they can "volunteer." At the Maynard Computer Mini-School, for instance, teachers had given up prep periods to have smaller class sizes and autonomy. This trade-off left them with little time to plan or learn to use technology. Most stay in at lunch with a subset of their students. Their only scheduled time in the computer room is with their students; during these periods, the regular classroom teachers tend to focus on classroom management while the technology coordinator leads activities.

Our teacher interviews suggest that for those teachers who have not adopted technology within their classrooms (or who have not added new technology uses they think would be powerful), the lack of time is the most-often cited impediment to doing so.

> *The difficulty for me is the time. I'm married and I have two kids.... It's a real juggle.... I spend at least 5 or 6 hours a week outside of school on the computer doing something.* —Elementary school teacher

Technology planners need to come to grips with the fact that only a small proportion of teachers will develop technology skills entirely on their own time.

Scheduling Technology-Based Activities

We have already addressed the various approaches taken by the case study sites to provide a high level of computer access to their students (e.g., placing computers in classrooms, rotating portable computer labs, extending computer lab hours). At these schools, students were reported to use computers, on average, for slightly more than 5 hours a week. This level of computer access far exceeds the average of 40 minutes per week that has been reported elsewhere (Becker, 1994) and is attributable to the relatively high numbers of machines within many of the sites, as well as careful scheduling (especially in locations with fewer computers).

The importance of scheduling goes beyond the provision of technology access per se, however. The kinds of technology-supported project-based learning activities that have been advocated by education reformers, and are featured throughout this study, require a different approach to scheduling than the traditional model of education. Rather than segmenting time rigidly into discrete subject-specific periods of teacher lecture and individual seat work, project-based activities require extended blocks of time as students move from one aspect of a multifaceted task to another and work (often collaboratively) to bring their project to fruition. The need for large blocks of time is especially true of projects in which technology is being used as a tool to support a variety of tasks. At a most basic level, it takes time to move to the computers, pull up the necessary files, engage in the task at hand (e.g., word processing, database entry, calculation), and then save the file or produce a hard copy of one's work. Within the context of a collaborative complex project, it takes time to orchestrate the use of different tools for different tasks, to provide one another with ongoing assistance and feedback, and to engage in the critical thinking and problem solving that such a project entails. For this reason, a number of the case study schools chose to structure the school day around blocks of time considerably longer than those used conventionally. At the elementary level, project-based activities comprised the bulk of the school day in many case study school classrooms. At the middle and high school levels, where instruction tends to be more specialized, some schools opted for 85- and 90-minute periods, as opposed to the more traditional 50-minute allotment. Teachers found these longer blocks of time and the attendant flexibility about how they used time with their students to be important for technology-supported work:

> *Especially when we're working in the lab, I've got time to demonstrate something, give them samples of it, let them make something, or do a little problem solving.*
> —Industrial arts teacher at middle school with block scheduling

One teacher who had been accustomed to using learning stations in his class had been using 20-minute rotations with his fifth-grade students. When he started bringing technology and more complex projects into his class, he found that he needed to extend these to at least 40 minutes and sometimes more. Schools participating in TeacherNet activities found that their 50-minute periods were not compatible with network activities. A number of them changed their schedules so that students could spend more time on the network. Schools with traditional short periods that did not make adjustments found that the short blocks of time hindered their efforts to involve students in meaningful projects that included technology use.

Providing Adequate Space and Physical Infrastructure for Technology

It's an unfortunate reality in many of today's schools, particularly those serving children from low-income homes, that there is often literally no room for technology. Some case study schools found themselves basing decisions about where to place computers as much on where the equipment would fit as on any pedagogical grounds. One school used a separate “activity room” for hands-on science activities and many of its computer activities because it was so hard to fit computers physically into the regular classrooms. Another school did not have the option of setting up a computer lab because there was no classroom to spare.

Power is an issue for even more schools:

> *At the site we were at previous to this, we didn’t have the electricity to run the computers.... We had 5 computers in each classroom, except one classroom that had 15 or 20 because they were on a different main line and they had the power to run the computers. If everyone had all five computers on at once, the fire alarm would go off!* —Elementary school teacher

Whereas schools housed in older buildings face such serious barriers in trying to introduce technology, new schools, designed with technology use in mind, experience both greater opportunities and potential pitfalls. South Creek and the School of the Future, the two case study schools totally renovated with technology use in mind, were able to include not only the proper wiring and power for computer and network use but also innovative features such as research labs structured around computer islands, spacious multimedia centers, and Discourse System classrooms resembling corporate training rooms. The disadvantage of some of these spaces became apparent, however, when there were changes in technology or in the way the room was used. For example, 3 years after the building’s renovation, the Discourse Rooms and some of the labs with permanent computer islands at the School of the Future were being used as regular classrooms—an arrangement that, at best, appeared to be physically awkward and, at worst, hindered classroom management and posed great difficulty for conducting some activities. Ideally, technology-using schools should be designed for flexibility, allowing for the changing physical requirements of equipment and the activities supported by it.

In addition to the limitations of space and power described above, more and more schools are facing severe restrictions as they seek to make use of Internet resources. Most schools have neither an adequate web of telephone lines and modems nor direct connections to wide area networks. Teachers, students, and administrators participating in the TeacherNet project, for example, nearly all spoke about the inadequacy of their access to the network, which at the time of our site visit (May 1994) consisted of banks of modems connected through phone lines. One teacher in a school with 1,400 students and a staff of almost 100 pointed out that the school had only eight phone lines. He reported that nearly every time he tried to use a telephone,

> *All the little red lights would be on. You can’t call out; you can’t call in. We just don’t have enough phone lines, and we can’t afford to keep buying more.* —Secondary school teacher

The lack of access has both direct effects—in that teachers and students who want to participate in telecommunications-based activities have to accept very long delays or forgo them altogether—and indirect effects—in dissuading teachers from getting involved in network activities.

> *When I get more access, I will use it more. When my access is so limited, it doesn't make sense to spend the time getting into it because Internet changes almost every day.* —Secondary school teacher

The problem of limitations in terms of the infrastructure for telecommunications activities is a widespread one that will become even more apparent as more schools agitate to "get on the information superhighway." Chris Dede writes in a recent paper (October 1994):

> Teachers' and students' access to the educational services now appearing on the Internet is problematic, because few schools have information infrastructures capable of routing data to individual classrooms. Unlike higher education, K-12 institutions typically have neither host computers powerful enough to allow direct access to the Internet nor a web of telephones and modems that could enable individual Internet usage through dialing up a provider. Further, many schools do not have networks that transmit data around the entire building, and the networks in individual classrooms often have such low bandwidth that sending educational material from computer to computer is very slow. (p. 11)

Currently, there is a great deal of excitement, uncertainty, and jockeying for position among corporations that would like to have their technology at the heart of the "national information infrastructure." Given both this degree of uncertainty and the amount of resources involved, it is difficult for individual schools to make optimal plans for developing a telecommunications infrastructure. Federal, state, regional, and district initiatives and regulatory policies will be critical.

Discouraging Vandalism/Theft/Unacceptable Use of Technology

Planning groups, administrators, and teachers contemplating the option of introducing technology sometimes argue against bringing it into schools on the grounds that there will be serious problems with theft or vandalism. In this regard, it is interesting to note how little problem our case study schools had in these areas, given the institution of reasonable precautionary measures. Despite the fact that many of the schools were located in low-income neighborhoods where graffiti is a common problem, the schools themselves created a sense of shared stake in the equipment and respect for it that was reflected in student behavior. A middle school reported that the only problem it has experienced was the occasional theft of mouse track balls, a nuisance they now prevent through a routine of having every student turn over the mouse at the end of class for a quick check before leaving the computer. An elementary school that has been using computers since 1980 reported having had only one theft in 13 years. The Apple Classrooms of Tomorrow (ACOT) program, which includes a take-home computer for every student, reported only one failure to return the equipment in 8 years. (Students cannot receive their school records if their computer has not been returned.) This is not to say that schools don't need security systems to safeguard their equipment. An elementary school that did not have a security system and that held many of its classes in portable units that are not very secure had 10 computers stolen over the years until the district installed a security system. The principal reports having had no theft or vandalism problems since the system was installed.

Educators and parents are concerned also over the potential for improper use of technology, increasingly so as the use of telecommunications becomes more common. They fear that students may use technology for destructive purposes, may get involved in hacker pranks, or may get access to inappropriate material while exploring the Internet.

> *There is so much stuff out there. There's information on pedophiles, pornography is rampant out there, and there is information on how to build bombs and how to kill someone without getting caught.* —Librarian in a TeacherNet school

Public concern about sexually explicit material on the Internet mounted during 1994 and 1995. While some media reports of the amount of sexually oriented material on the Internet appear to have been blown out of proportion (O'Connor, 1995), the potential for problems intimidates many schools and teachers.

At a recent workshop for teachers in a special project bringing Internet resources to all high schools in a city district (not one of our case studies), one teacher came up with the idea of reducing risk by allowing only two specially appointed, trustworthy students to have firsthand access to the Internet. Despite the fact that the intention of the innovation was to give all students technology-supported learning opportunities, the idea spread like wildfire among teachers who feared embarrassing incidents.[4]

Most of our case study schools did not appear to have serious problems with students' exhibiting inappropriate behavior or misusing technology, but the issue does require attention and constant monitoring. The most productive way to think about these issues appears to be within the more general context of school climate. A number of the case study schools were

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4. New products and services offer a degree of control. America Online, for example, will not provide an unrestricted account to anyone under 18. Subaccounts available to younger users are restricted to those activities parents approve for their kids. Several groups are working on rating systems for World Wide Web sites and on programs that can restrict access to sites with ratings appropriate to a given age group.

making great efforts to teach students how to work cooperatively and to show respect for each other and each other's opinions as part of their school reform effort. Logically this ethic extends to communication over the network and to the way in which equipment is shared with other students. During the site visit to one school, two girls who were good friends became embroiled in a tiff and exchanged angry e-mail notes that included insulting language. Their teacher and the technology coordinator reviewed the messages and planned the counseling that they would give the girls. At another school where the students had been involved in a special program to teach skills for working with others and giving constructive criticism, e-mail messages showed the pains that students took to give "helpful, thoughtful" comments rather than put-downs for ideas developed by others.

> *We all like the number system* [that the group posting the original computer message created for their hypothetical culture], *but we want to know how the number 0 looks like, and you can do more numbers not just ten like we have right now.* —Group of fifth/sixth-graders working with CSILE

Teachers involved in the program stressed that comments like the one above are the result of much modeling, support, and practice. The computer itself aided the process of developing these communication skills, as the teachers were able to review the running records of students' electronic-mail exchanges, allowing them to provide specific examples and critical feedback.

One of the high schools participating in the TeacherNet project had a formal technology use policy that provided an honor code for use of equipment and the network. Each student, along with his or her parents and a sponsoring faculty person, had to sign an application that included a detailed discussion of "Netiquette" before receiving their e-mail accounts. The discussion addressed basic guidelines for network use (e.g., not writing or sending abusive language; not revealing personal address, password, or phone) and made sure that both students and parents understood that the network was not private and that it contained inappropriate material. Both teachers and students (in separate focus groups) reported that the policy worked well overall.

There were significant problems with misuse of technology at one of our case study sites, a school where the general school climate had deteriorated to such an extent that students and teachers appeared mistrustful of each other and of their respective peers. Students evidenced a great deal of concern about their passwords. One student said that he used a 55-letter password in order to protect his files. Students said that destruction of their computer files at the hands of other students was an ongoing concern. Students reported also that teachers limited their use of telecommunications because of problems with student hacking.

The fact that this school's experience was so atypical within our case study sample suggests that technology access does not in and of itself lead to a hacker mentality, but it does provide a cautionary tale suggesting that school communities need to develop, promulgate, and enforce codes of conduct for technology use.

The best antidote to the in-house misuse or abuse of equipment is its use within projects that students value as meaningful and worthwhile. At many of the sites, students took great pride in work that they were able to accomplish with the aid of technology. During interviews, students often noted that they were "lucky" to have access to such sophisticated tools. This attitude of pride and accomplishment goes hand in hand with sharing in the responsibility of caring for the equipment.

Coping with Hardware and Software Change

As projects mature, they face a new challenge in terms of changes in both hardware and software. A number of our sites were grappling with these issues and appeared to be somewhat surprised by the extent of the difficulties posed.

> *We have continually upgraded the machinery and software since we began. We've been through three or four versions of MacPaint and now use Canvas as a drawing program; three or four versions of MacWrite and AppleLink.... Just as soon as you think you've got a handle on something, it disappears or version 4 comes out.* —Elementary school teacher

The frequency of changes in available software and what students are likely to be using means that teachers, like other professionals, can never expect to complete their learning in the technology area. One implication is an ongoing need for technical assistance and time for learning new technology. Nevertheless, coping with your 14th new piece of software is certainly easier than it was with your first major change, and with time teachers begin to face the inevitable changes with more equanimity.

> *I used to spend a lot of time, when we began, preparing step-by-step lessons that were 42 pages long, where the kids would check off their computer lesson as they came through ("Did you do this step?"), and now I just don't even bother, because they can only be used once* [because of software changes]. *And a lot of times the kids skip through steps that they already know. I think it really reflected growth in our confidence to be able to say, "Well, this is how you do it. Let me know when you get stuck." The printed directions are much less mechanical and often ask for student input and record keeping, which they individualize to their particular project needs.* —Elementary school teacher

Whereas new software and hardware call for new learning and flexibility on the part of teachers, old hardware and software pose other difficulties. One of the surest effects of introducing new technology is the creation of a "technology appetite" on the part of both teachers and students. As soon as more powerful computers are introduced, no one wants to use the older, slower machines. Even if the school does not get new hardware, teachers' and students' technology activities will lead them to read about newer technology available elsewhere, with an attendant frustration if they cannot have the same technology in their own school.

The superintendent in the district that set up South Creek Middle School as a model technology-using school expressed some frustration at the fact that the technology purchased for the school (over $2 million) remained state of the art for such a brief time, less than 3 years. Basically, the school's entire computer inventory was purchased for its opening at a time just before System 7.0 became standard for Macintoshes. Although the school has well-designed local area networks and a T-1 connection to the state's wide area education network, several school staff expressed frustration over the greater speed available at some other schools.

> *While some schools are getting on the information superhighway, we're going to be on a dirt road.* —Teacher at technology middle school

Another teacher echoed this sentiment:

> *We're constantly trying to get updated. Because as soon as you get the computers, you're outdated. Boom! Something else comes out. So we are constantly buying new programs or upgrading our computer systems and it's getting harder to get the funds. You know, "Well, we just gave you this...." And yes, we're appreciative, but now we want to take it a step further. Because our kids have done well with it and we want them to go a step further with it.* —Middle school math teacher

Students, too, acquire an awareness of the rapidity of technology changes and the hopeless effort to keep up:

> *There's a lot of things* [we would like to have] *like...notebook computers. It's kind of hard because the school only has a limited amount of money and you can't always get the new things. But then you kind of regret it, because in the future your kids are required to have a notebook computer instead of a pad of paper. It's like paper won't be used any more. That's the old stuff. Medieval! That's like way back!* —Fourth-grade student

Schools and districts are learning to cope with the equipment obsolescence problem in several ways. One important activity is a careful analysis of the various uses for which equipment is desired. Many uses do not require powerful equipment or telecommunications connections. Older equipment that would not be useful for Internet applications can be fine for early writing or learning keyboarding skills, for example. Allocation schemes that make the more powerful equipment and applications readily available when they fit the task at hand while making good use of older equipment can result in large cost savings.

A second important aspect of coping with hardware and software changes and obsolescence is to expect them and plan for them. One district superintendent criticized districts who were using 15-year bonds to finance the purchase of equipment that was sure to be obsolete in 5 years. An elementary school principal, coming to grips with the increasing maintenance costs for the school's aging stock of computers counseled:

> *Schools have to know when they are going into technology that there is a cost beyond the buying of equipment, that industry understands. Industry builds in that cost; they build in obsolescence; they build in upgrading; they build in repair. But schools think they have a one-time expense.* —Elementary school principal

Planning for Transitions Across Programs and Schools

For the technology-rich schools featured in this study, a high level of access to a wide array of equipment has resulted in what one teacher referred to as "technology-hungry students." These students are skilled and comfortable in their use of technology and find ways to incorporate it into their work as a matter of course, often exceeding the initial expectations of their teachers in the process. The students we observed clearly took pride in demonstrating their technical knowledge and expertise. They appeared particularly pleased with the notion that their skill level exceeded that of many adults (parents in particular). When asked during interviews how they would feel if the technology were taken away, the nearly universal response was one of great dismay and protest. Some students stated that they had become so accustomed to working with computers that having to do without them would be (or had already been experienced as) frustrating and painful.

For many of these students, technology has become an integral part of their learning process. This raised an issue of concern for several of the program innovators we spoke with regarding what would happen to these students when they enter programs that are not well enough equipped to provide follow-up. Students leaving technology-supported elementary and middle schools may find that they do not have the opportunity to build on the skills they have developed. At one of the case study sites, in particular, students who had previously graduated returned to their former school to gain access to the technology. The problem of students transitioning out of a technology-rich program generally involves more than one school. District involvement in this issue is therefore very important.

Replication and Dissemination to Other Sites

The technology-supported projects described in our case studies represent a new vision of teaching and learning, altering the shape of classrooms as we have known them in the past. This vision needs to extend beyond isolated model programs, however, if it is to have a significant impact on the state of education. The ultimate goal of education reform is to provide *all* students with lifelong learning skills and a meaningful preparation for the future. Many schools and districts across the country are struggling to define these goals within their own particular settings. Although each path to reform is unique, there is much to be gained from the experiences of the trailblazers—those schools (such as the ones featured in this study) that have taken a lead in the implementation of technology-supported reform. These early innovators have valuable stories to tell, offering a wealth of information regarding lessons learned, successes achieved, and obstacles overcome. Their classrooms offer concrete examples of technology-supported teaching and learning in action.

The extent to which the stories of the case study schools were being shared with others varied from site to site. In some cases, a plan for dissemination was an integral component of a project's implementation. The mini-school at East City High School, for example, now conducts a teacher development center (supported by both Apple and a federal grant), which offers summer institutes and 1-week practicum during the school year to teachers from across the country. The purpose of the center is "to give the participants those experiences they will need to implement similar instructional activities in their own classrooms/schools/districts." Training is provided by four East City High teachers, who model technology-supported instruction and provide follow-up support to hands-on activities. Students also participate in the institute so that attendees have the opportunity to observe and use technology within the context of teaching.

For most of the case study schools, a continuous stream of on-site visitations and the professional activities of the staff (such as the conference presentations, committee memberships, and publications) have served as the primary vehicles for dissemination. Media attention has also aided the process of dissemination (although for some programs, too much attention too soon has led to difficulties). In several sites, individuals within the school have been particularly adept at gaining program visibility, which in turn has led to increased requests for visitations and for information regarding technology implementation. The coordinator at the Maynard Computer Mini-School was one such individual. In addition to conducting numerous interviews and conference presentations, he created a home page on the Internet World Wide Web with periodically updated information about the computer mini-school's activities. This same individual was recently awarded an Apple leadership grant to replicate components of the mini-school's computer network/lab at another site. He has also received a separate corporate grant to produce a publication on the use of technology in teaching. Corporate partnerships have funded a range of dissemination activities within a number of the sites, including teacher participation in conferences, the production of materials featuring exemplary technology projects for widespread distribution, and arranging for media coverage. In some schools (such as East City High), outside funders have been the primary source of support for dissemination.

The major obstacles to dissemination are the lack of funds and time. The process of implementing technology and reform within their own sites makes tremendous demands on administrators and teachers. Not surprisingly, most schools are not ready to engage in dissemination activities until their programs are well established. Even at this point, it is difficult to take on this added task if additional funds and support specifically designated for this purpose are lacking. This was certainly the case for several of the sites we visited. For these and other reasons, the issue of dissemination to other schools within many of the case study sites' districts was particularly complex and sometimes problematic.

The principal at South Creek reported that the reopening of her school as a technology-rich program set into motion a wave of envy on the part of other schools' administrators and teachers, who began requesting that the district equip their schools with technology as well. She commented that, in contrast to forcing technology on sites that had previously expressed no interest, the instigation of "the green-eyed factor" served as a "brilliant strategy" for getting schools interested in technology use. South Creek teachers have offered a series of technology in-services to other teachers throughout the district. The school has hosted a technology conference and has piloted a state program for career exploration through technology. The principal has played a key role in orchestrating these initiatives, which she has viewed as the opportunity to give something back in return for the support provided by the district and state.

In this case, the increased desire for technology on the part of other schools was reported as a positive side effect of "the green-eyed factor," helping set the stage for the dissemination process. More often than not, however, jealousy and resentment stemming from the perception that the case study sites have been provided with more than their fair share of resources have interfered with relations with other schools, making dissemination within districts more problematic. At the School of the Future, the impressive amount of technology and year-round teacher positions became the source of a great deal of criticism and envy within the local education system. As the school struggled through the early phases of pulling together a new program, heavy public scrutiny led to decreasing credibility and diminished support within the community. The restructuring coordinator at another site reported that her school's faculty had the reputation among other teachers within the district as being "elitist," in part because of their success in attracting outside funds to support technology use. In her view, this perception slowed the local dissemination process, which she characterized as "the weak spoke in the wheel."

The same factors can impede dissemination even within a school. The school-within-a-school programs at Maynard Elementary and at East City High School have had negligible impacts on the schools in which they are housed. A district administrator at the latter site commented that the technology-supported program was a "stand-alone enrichment environment" (in terms of its influence at the school level), despite the staff's diligent efforts to open their doors and share their expertise with other East City High teachers. His perception was that the teachers outside the program did not take advantage of these offerings because they felt that the teachers within the program "had it easy" given their resources and the fact that their afternoons were available for planning.

Administrators and teachers involved in the implementation of new programs stress the importance of taking a proactive stance toward providing information regarding their activities and maintaining ongoing communication with the district and with the local community as a way to avoid and address some of these difficulties. Many sites reported having to deal locally with misinformation regarding the acquisition and use of funds to support technology and other program features. A common misconception was that technology installations and special programs were paid for primarily with district funding, thus reducing the funds available to other schools. In many cases, however, technology implementations were funded through corporate partnerships, special grants, and other sources external to the district. Interestingly enough, three of the case study schools receiving higher levels of district support than most reported the fewest problems in terms of relations with local schools. When districts invest in this level of technology-supported reform at a single site, they may also be more likely to have a stake in paving the way for dissemination (although this was not always the case).

Nathaniel Elementary's school district provides one example where district-initiated reform was coupled with an ongoing commitment to the spread of innovation. Each year, a new cohort of schools has been funded for restructuring and technology implementation through the district's Demonstration School project. A "Teacher on Special Assignment" (a district-funded position) assists schools with the restructuring process, particularly in the areas of technology and curriculum. An important part of this process has involved learning from the experiences of the other sites. Having an individual who visits each site and is familiar with their activities aids the dissemination process. Each school has been encouraged to take its own path to reform while incorporating whatever elements from other sites they might find useful. The district has also initiated monthly meetings for teachers and for technology leaders from the participating schools, providing opportunities for sharing, feedback, and support. At the time of our site visit, the district was putting together plans for a wide area network that would supply further linkages between schools.

The district is in a critical position to support dissemination once a project is under way. Districts can assist with the sharing of information and expertise and with the formation of partnerships between schools. Some of the districts within our study filled this role in various ways, for example: funding in-services taught by computer-using teachers, setting up mentorship teacher programs, providing teachers with opportunities to observe technology-supported classrooms, bringing administrators and teachers together from across sites to discuss technology implementation and reform, and setting up wide area networks.

The state can also play an important role in supporting replication and dissemination to other sites. Bay Vista Elementary was funded by the state to serve as a model technology school to other schools within the district and across the state. The school's mission was to focus on technology use in the area of science, while additional sites were funded as model schools in other areas of the curriculum. Once the technology-supported science curriculum was implemented and certified as aligned with the state framework, the school was funded by the state for 4 years of dissemination activities. Bay Vista teachers demonstrated the use of technology in science through visits to other schools and by having teachers from other schools visit their classrooms. A computer cadre at the district level was formed so that there would be at least one teacher in each school who had a high level of exposure to the Bay Vista program, which they in turn could share with their fellow teachers. State funds support the position of a coordinator to take responsibility for orchestrating many of the dissemination activities, as well as a part-time consultant to maintain a model site for visits and training. The school has produced a series of materials and videotapes on integrating technology into the science curriculum. By 1993, 55 projects adapting portions of the program had received education technology grants from the state department of education.

Sustaining the Innovation

This chapter opened with a discussion of the challenges that schools face in trying to get a technology-supported education reform initiative up and running and will close with a discussion of the problem of sustaining the innovation. Schools in our case study sample had been serious technology users for as long as 12 years at the time of our site visits. Certainly, several of the innovations could be considered "mature" (although they never held still in any one form). The equipment maintenance and obsolescence problems discussed above are just some of the issues facing the more mature sites. Problems in maintaining a common vision, unity, and the social infrastructure around reform and technology use are more complex.

One problem is the level of difficulty of what education reformers are asking teachers to do. Constructivist approaches to teaching are quite simply more demanding. Some have argued that it is unrealistic to expect all teachers to do this kind of teaching all the time, no matter how strongly they have internalized constructivist principles. In addition, learning to use technology and designing worthwhile instructional activities that incorporate it are time-consuming. Especially in situations where no system of support for these activities has developed and teachers must use their own time if they are to participate, teachers are likely to grow weary of the effort. But even in well-designed and well-supported projects, it can be difficult to *maintain the spirit of innovation*. External sources talking about one of our case study sites that had been using technology intensively for 8 years reported that teachers were no longer putting in the extraordinary effort and energy they had brought to the project in the beginning. Afternoons set aside for collegial planning were no longer being used in that way. Experiencing less support at the district level and several years without the infusion of new equipment, teachers had ceased to show the level of creativity in their instructional uses of technology that had characterized earlier years of the program, according to some observers. A recent resurgence of district interest and acquisition of multimedia equipment has rekindled some of the program's energy and creativity, but has not brought it back to the level experienced in the first few years of the program.

Many innovations depend greatly on a single individual to champion and protect the program, to pull teachers together, or to provide necessary technical expertise. Quite a number of our sites had faced or were facing situations in which a *change in leadership* at the project, school, or district level or the cessation of funding left them vulnerable.

Given the inevitable changes among administrators, staff transfers, and retirements, projects that have not evolved into sharing of technical knowledge and the development of multiple sources of leadership and enthusiasm will have a hard time sustaining themselves. The key appears to be a solid core of participating teachers. One case study elementary school described how their use of technology had survived the principalship of someone who did not like the idea of technology in schools and who would in fact avoid hiring anyone with this interest. With their external funding for technology-based activities and support from each other, technology-using teachers quietly continued their activities. Another case study school lost the majority of its external funding for technology projects and support positions between our first and second site visits. Nevertheless, the commitment of the teaching staff to the school and technology's role in it appeared to be carrying them through:

> *The staff has never been more together than they are this year; there is a real cohesiveness.... Aren't they something else?.... And while it's a shock after 7 years to have all that support taken away, in some respects it has given the teachers a better understanding about their own abilities, knowledge, and capabilities. Since then, six teachers have been trained by Apple so that we are now an Apple service center. That would have been unheard of years ago. The teachers would not have thought that they were capable of doing those kinds of things.* —Elementary school principal

6. RESOURCES FOR TECHNOLOGY IMPLEMENTATIONS

In this chapter we consider the hardware, software, and personnel resources needed to implement technology-supported programs like those observed at our case study sites. By examining the range of resources and expenditures for those sites, we hope to provide school and district planners with a clearer sense of what is required for a significant, well-planned implementation of technology.

The case study sites varied considerably in the length of their history of involvement with technology, as shown in Figure 2. (The figure is based on the eight single-school sites only; the TeacherNet schools are not included.) As described in the profiles in Chapter 4, they differed also in the particular goals that they hoped technology could achieve, and the ways in which they used technology. Some of the sites put considerable emphasis on video and multimedia technologies, for example; some emphasized use of wide area networks, and others did not. Across all sites, however, the vast majority of technology-supported activities involved computers, and in the next section we describe the level of computer equipment at these schools in comparison with national norms.

Computer Resources

Becker's (1994) analysis of data from the 1992 IEA survey Computers in Education provides a context for interpreting the quantity and allocation of computers in our case study schools. The survey data suggest that, despite an increase on the order of 3 million computers in schools between 1989 and 1992, the average number of students per computer in America's schools remains at a level that makes adequate access problematic. Becker reports that in 1992 the average (median) elementary or middle school had 1 computer for every 15 students, while the typical high school fared a bit better with 1 computer for every 10 students. Moreover, these figures are deceptively positive, given the large quantity of obsolete computer equipment in schools and the fact that large numbers of computers may sit in laboratories where they receive relatively little use (Schofield, 1995).

As Table 5 illustrates, most of our case study schools were considerably better equipped than the average American school, even allowing for the fact that our data were collected for 1993-94. The five best-equipped schools in our sample had one or more computers for every two students.

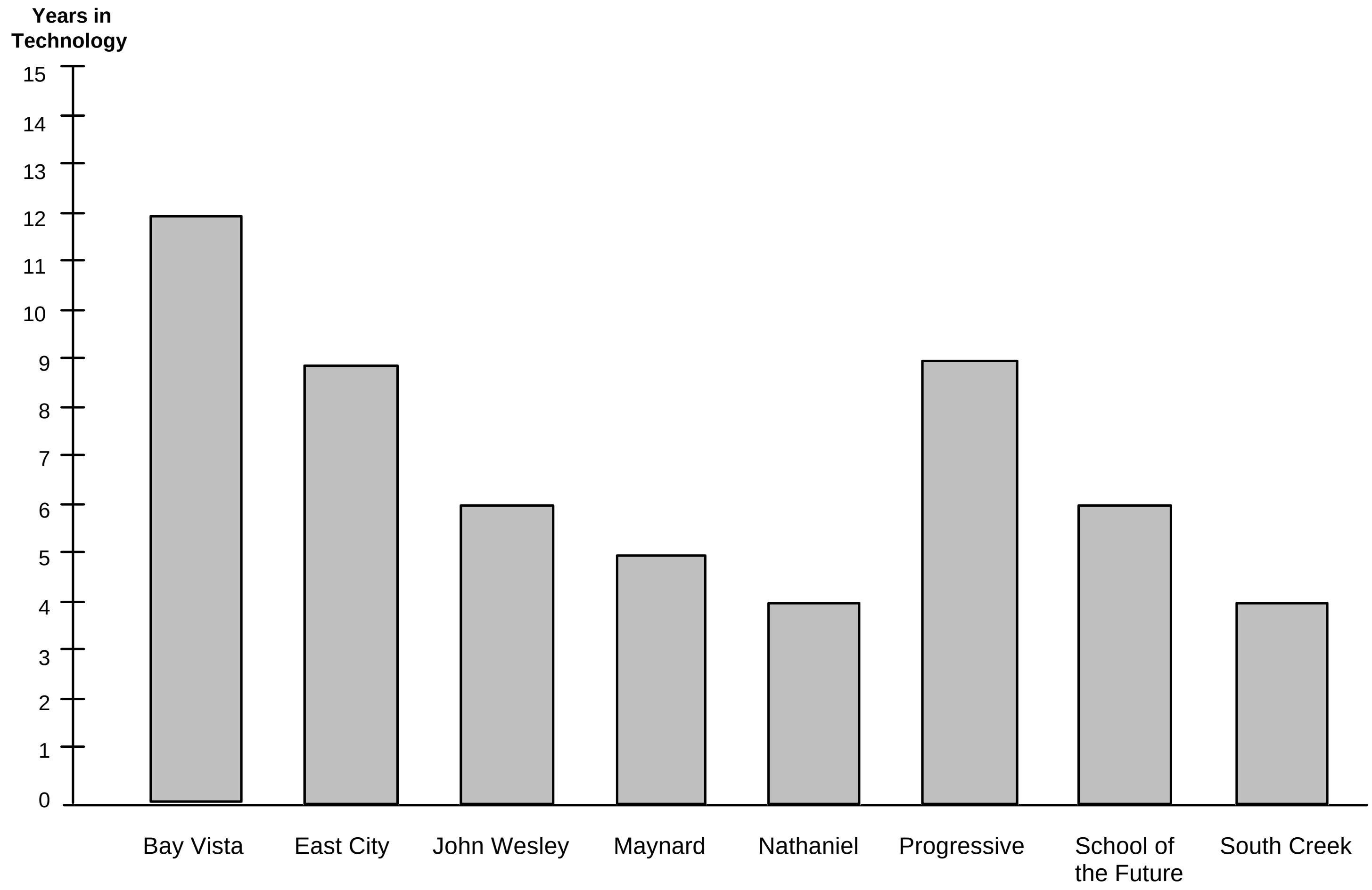


FIGURE 2. NUMBER OF YEARS EACH SITE HAS USED TECHNOLOGY ON A LARGE SCALE

School Year 1993-1994

Table 5

DENSITY AND DISTRIBUTION OF COMPUTERS IN CASE STUDY SCHOOLS

School	Level	No. of Com-puters[a]	Student: Computer Ratio	Computers per Classroom	No. of Computer Labs	Mobile Labs	Teacher Home Use	Student Home Use
Bay Vista	E	57	12 : 1	2-4	1	Yes	No	No
East City[b]	S	295	1 : 2	36[c]	NA[c]	No	Yes	Yes
John Wesley	E	122	7 : 1	3-5	1 (sp. ed.)	Yes	Yes	No
Maynard[d]	4-6	83	2 : 1	1-2	2	No	No	No
Nathaniel	E	176	8 : 1	3-9	1	Yes	Yes	Yes
Progressive	E	200	2 : 1	30-32[d]	0	No	Yes	No
School of the Future	M	136	1 : 1	1-12	3	No	Yes	No
South Creek	M	400+	<2 : 1	5-6	6	No	Yes	No

a As of school year 1993-94.
b School-within-a-school program only.
c Four computer-equipped classrooms are used interchangeably by all project teachers.
d Per double classroom of 64 students.

The school-within-a-school program at the secondary level, in fact, had two computers per student, a take-home computer for each student plus enough computers at school for all students to use one.

In addition to total number of computers per school and the ratio of students to computers, Table 5 shows the allocation of computers in our case study sites. For each school, the table shows the average number of computers in regular classrooms and the number of computer labs that the school maintained. The data suggest that, with the exception of Maynard, the schools in our sample did not rely primarily on labs as the mechanism for providing students with computer access. Our case study schools differed in this regard from the majority of American schools

(Becker, 1994). Most of the case study sites tried to have enough computers in regular classrooms that computers could be used as one of the “rotations” for a quarter or more of the students.

Finally, the table addresses the issue of home access. A number of sites stressed the importance of giving teachers access to technology where and when they have the most time to learn about it and to use it to enhance their own productivity—that is, at home after hours. Six of the case study sites provided take-home computers for teachers. Only two sites had ongoing programs of supplying students with computers for their home use, although several additional sites had experimented with take-home computers (usually older models).

Network Resources

In 1993-94, seven of the eight single-school sites in our sample had connected at least some of their computers into local area networks (LANs). Moreover, in five cases these LANs were general purpose rather than dedicated integrated learning systems. It is helpful to compare these reports with survey data cited by Becker (1994) showing that 44% of public elementary schools and 66% of high schools had LANs in the 1992-93 school year. Seven of the eight sites also had wide area network (WAN) connections, including one that had a World Wide Web (WWW) server. Table 6 summarizes the network resources and activities at our case study sites. In the 1993-94 school year, however, only three of the case study sites had implemented a client-server network model that made a wide variety of software available to multiple classrooms, provided folders for individual student and group work, and provided electronic communication throughout the school or mini-school.

During the year of our primary data collection (1993-94), only two sites had direct connections (not modems) to a wide area network. The involvement of these schools in wide area network activities is changing rapidly, however; two additional elementary schools had solid plans for extensive use of wide area network resources in 1994-95, and most of the other sites were in the process of addressing the issue.

Costs: Required Resources

Initial purchase of the technology hardware itself is the most obvious cost of these programs, and the one cost that appears to get the most attention. Although the weight of this purchase should not be slighted in times of tight school budgets, one of the lessons of the case studies is the fact that the initial hardware purchase should be regarded as only a fraction of the investment required to support an effective program. In addition to the initial hardware, there are costs associated with software purchases, telecommunications connections, maintenance and repair, teacher training, and system upgrades and obsolescence.

Table 6

NETWORK RESOURCES IN CASE STUDY SCHOOLS

School	LAN	WAN	ILS Uses
Bay Vista	14 Macs networked	Modem/phone lines	No
East City	MacJanet via Ethernet	America Online, CompuServe, AppleLink via modem	No
John Wesley	Ethernet	Modem/phone lines	No
Maynard	Gateway 2000 File Server	Internet server to WWW, Gopher via high-speed data line and client-server model	Yes
Nathaniel	AppleLink via modem, QuickMail	Modem/phone lines	No
Progressive	AppleLink	AppleLink via modem	No
School of the Future	AppleTalk	12 Apple modems	Yes
South Creek	Macs networked	12 modems; T-1 line provides access to state education network and Internet	Yes

Cost data are difficult to gather from schools and were particularly difficult in these case studies because many costs were assumed by external agents (e.g., corporate partners), absorbed by teachers (e.g., in volunteering their own time for training and materials development), or subsumed under larger cost categories that precluded itemized accounting of technology-related costs.

The approach used by Hank Becker (1993) offers a useful alternative to trying to estimate the costs of such innovations on the basis of the often incomplete cost data reported by case study informants. Becker used a survey of computer-using teachers not to ask about technology costs directly but rather to identify features of schools in which exemplary computer-using teachers work. Teachers in Becker's sample who used computers to provide students with project-based learning opportunities involving challenging, authentic tasks were more likely than other computer-using teachers to be in schools that:

- Provide a strong social network of computer-using teachers.
- Have a full-time technology coordinator who promotes computer use among teachers.
- Receive district support for in-service training, both in tool uses of computer software and in technology uses pertinent to particular subject domains.

- Stress student use of word processing in all their subject matter classes and for extracurricular activities (e.g., school paper).
- Institute policies for equitable access to computers across genders and ability levels.
- Use computers in subjects such as social studies, fine arts, and business and industrial arts, as well as in the core areas of mathematics and language arts.
- Face maintenance and coordination problems that are not issues at schools with lower levels of technology utilization.
- Feature smaller class sizes for computer-using teachers.

The features Becker identified for schools in which exemplary computer-using teachers teach are quite similar to those of our case study schools, with the exception of smaller class size. Only one of our case study sites, a mini-school set up with the express purpose of reducing class size, had smaller-than-usual classes. This is not to say that smaller class sizes would not have helped teachers implement project-centered instruction with technology tools—only that we observed teachers using this approach with classes of over 30 students by setting up class organizational structures within which students were divided into different self-directed groups working on different activities at any one time.

Having identified features of schools with exemplary computer-using teachers, Becker then provided rough estimates of the costs associated with implementing these features. Although some of the specific assumptions behind Becker's cost estimates were not characteristic of our study sample (specifically, the class size assumptions), we find the overall approach illuminating and particularly like the fact that it encourages administrators and planners not only to think about the *broad array of support costs needed to implement technology effectively* but also to think in terms of *annual rather than one-time costs*.

Table 7 is based on Becker's general approach, but it incorporates different assumptions about (1) the number of teachers per pupil in a representative school, (2) the number of technology coordinators and support staff needed, and (3) the overlap between staff development and technical support activities and specific areas in which teachers need support. (Becker treated support for word processing use, equity, and new subject matter uses as separate cost categories.) The figures shown in Table 7 are not based on actual expense data provided to us by schools but rather are estimates of what a school might expect to spend to initiate the kinds of activities we observed. As indicated above, outside sources of funding should be explored as ways in which costs to the general education fund might be reduced.

Table 7

COST ESTIMATES FOR IMPLEMENTING TECHNOLOGY-SUPPORTED EDUCATION REFORM

Cost Element	Explanation	Annual Cost
PERSONNEL SUPPORT		
Technology coordinator	1 FTE to coordinate and support teachers in planning technology implementations.	$50,000
Maintenance/ technical support	.5 FTE to support 30 teachers and 800 students (technology coordinator performs some support functions also).	$25,000
Teacher networking time	Time for teachers to work together in planning and organizing technology use; time to share information on instructional uses of technology: 2 hours/week x 30 teachers.	$75,000
Teacher access time	Time for teachers to use school technology in developing instructional activities and to support professional activities: 400 hours per year.	$50,000
Formal staff development	Formal instruction for groups of teachers. Includes release time and trainers' salaries: 2 days/year for 15 teachers.	$15,000
EQUIPMENT AND MATERIAL		
Computers	Assume purchase of new computers for 5% of students per year. Assuming 5-year equipment life and goal of attaining a 4:1 student-to-computer ratio, a steady level of equipment purchase is projected. Estimated cost of $1,600 per computer.	$64,000
Other hardware	Items such as printers, video equipment, network cabling. Estimated at $750 per classroom.	$22,500
Software and related	Assume network versions of 10 new pieces of software @ $1,000 each plus one or more high-end pieces of software.	$30,000
Telecommunications	Network connection/connect time.	$12,000
Maintenance	Estimated as 3% of capital expense of equipment over a 5-year period.	$12,975
INFRASTRUCTURE	Wiring, furniture, etc. amortized over 10 years.	$13,600
TOTAL		**$370,000**
TOTAL COST PER PUPIL		**$463**

Note: Hypothetical school of 800 students and 30 teacher FTEs.

Source: Table is based on Becker (1993); Tables 1 and 2, pp. 33 and 34. We are indebted to Becker for the classification of cost categories. The assumptions concerning the number of staff per pupil and the level of staff support required for exemplary technology implementations are our own, based on the experiences of our case study sites. We differ from Becker also in assuming use of computer networks and network versions for software. Thus, our projected per-pupil costs are significantly lower than those provided by Becker.

The recommended estimates provided in our table can be compared to cost data collected recently by RAND in a study of the costs of high-technology programs (Keltner and Ross, in press). Recent expenditure histories were gathered from nine schools (Keltner, 1995). In the RAND study, per student costs averages $350 a year. The major difference between the RAND data on actual expenditures and our recommended levels of expenditures in Table 5 lies in the area of personnel costs. Personnel supports for technology in our table are estimated at $269 per pupil per year or 58% of the total costs related to technology implementation. This emphasis on the human support structure is consistent with the recommendation made by policy analysts (e.g., David, 1994) that at least half of the funds for educational technology implementations should go to training and staff support. In contrast, the schools studied by RAND spent an average of just $24 per pupil annually for staff development and technical assistance for technology use. This figure is less than 7% of the schools' total expenditures for technology.

In part, this difference may reflect a failure on the part of many schools to provide the needed human infrastructure for their technology innovations. Part of the difference, however, probably lies in schools' tradition of expecting teachers to improve their skills on their own time. Many of the schools in our case study sample spent less than the figure in Table 7 for teacher access and planning with technology because teachers performed these functions on their own time. It was common for us to observe teachers meeting at 7:00 in the morning and then again until 7:00 or later at night to work on technology-related activities and issues. While such volunteerism reduces the costs to schools, the personnel costs are real from an economic perspective, whether they are borne by school budgets or by the teachers. Systemic reform efforts will be on shaky ground if they rely on this level of uncompensated dedication from teachers. Certainly technology implementations will be limited in scope if they include only staff with this level of flexibility and commitment.

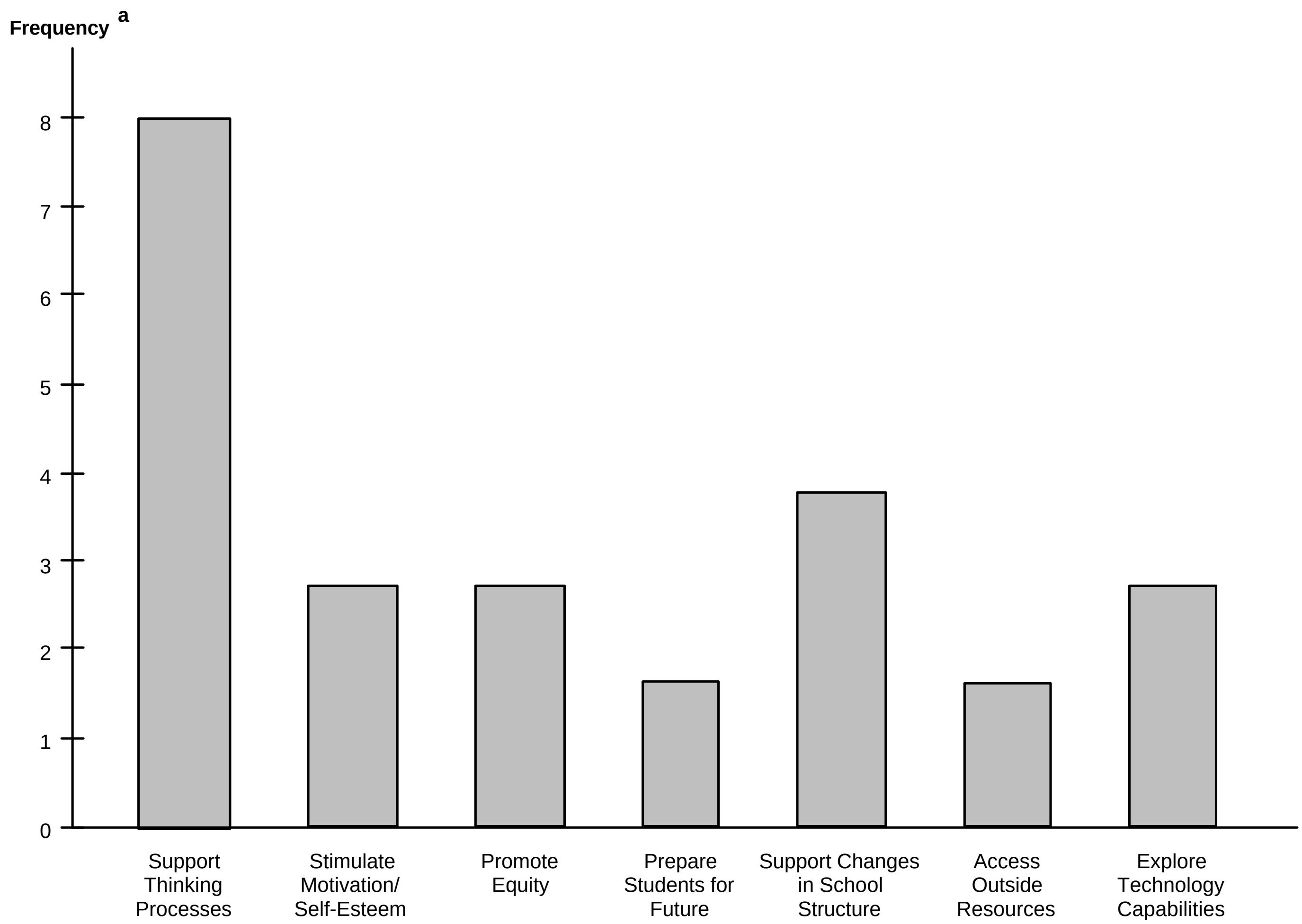
7. LEADERSHIP FOR TECHNOLOGY IMPLEMENTATIONS

There is no one road to either technology implementation or school reform. Depending on the local context and the nature of the leadership emerging within the school community, innovations can take many paths and evolve from many roots. In this chapter, we provide a summary of the characteristics of technology-supported education reform implementations at the nine case study sites. Although the relatively small number of sites and the way in which they were chosen precludes us from claiming that the frequency of any one feature among our case studies is indicative of national trends, the degree of variety among our case studies is instructive.

Incentive for Technology Use

In many locales, there is good support both within the education system and among the general public for introducing technology into schools. Electorates that have been reluctant to support education funding generally are sometimes more favorably disposed toward school bonds when they are designed to finance technology. Technology can play many different roles, however, and this generally favorable attitude toward technology use is not always connected to a clear set of objectives for the technology implementation. Since the particular choices of hardware and software and the way that they should be implemented and supported depend on the objectives, it is important to discuss and understand these as part of the initial planning and bid for public support.

Our case study sites represent a range of motivations for instituting technology. Most sites had multiple goals in mind, as shown in Figure 3. In general, the rationales described by our sites fall into six major reasons for bringing technology into classrooms. First was a belief that computer-based technologies could provide *support for thinking processes*. At the Maynard Computer Mini-School, for example, the use of instructional software designed to teach problem solving (e.g., *Rocky's Boots*) was a primary reason for investing in technology. Technology innovators at another setting viewed their use of a multidistrict network as a means "to develop students' reasoning strategies so that students can better access, organize, and integrate diverse sources of information to solve intellectual challenges and accomplish complex tasks" (TeacherNet Guide). Throughout the case study sites, many respondents stressed the opportunities that technology provides for acquiring critical-thinking and problem-solving skills—both through the use of software specifically designed for this purpose (including



[a] Among 9 case study sites.

FIGURE 3. MOTIVATIONS FOR INTRODUCING TECHNOLOGY AT CASE STUDY SITES

open-ended exploratory software such as LOGO) and through the many requirements for solving problems that naturally emerge as one is using computer tools to accomplish a range of tasks (e.g., selecting appropriate software, figuring out what to do when the system doesn't behave as one expects it to). Several teachers described their goals for the use of technology in terms of the support that it could provide for acquiring complex concepts, for example, by graphically representing abstract concepts such as acceleration or by providing scaffolding for concept building, such as the cognitive prompts embedded in CSILE (Computer-Supported Intentional Learning Environments).

A second frequently cited rationale for introducing technology was to *stimulate motivation and self-esteem*. Through either personal experience or a review of the literature, many innovators perceived the dramatic effects that technology can have on students' interest in class activities and their sense of their own capabilities. Although these benefits are perceived as occurring across the board, our case study sites, most of which serve student bodies coming predominantly from low-income homes, felt that these benefits would be particularly important for their students. Thus, a related reason for using technology was the *promotion of equity*. In the case of the teacher network, the districts recognized the wide disparity in the resources available to them and felt that a unifying network could promote a more equitable use of those resources. In the case of several schools serving students from low-income homes, technology innovators stressed the importance of giving these students the technology tools that would equip them with a needed edge to compete with children coming from more affluent homes, where technology is commonplace.

> *As soon as I heard that* [South Creek] *was opening up and it was going to be a technology school with the majority of kids being minority kids and low SES kids, I wanted to come here...* —Middle school mathematics teacher

The concern for equity is related to a fourth major motivation for introducing technology—to *prepare students for the future*. Within each of our sites, respondents foresaw a future in which both higher education and the world of work would be infused with technology. These educators argue that schools have a responsibility to give students—and especially students from low-income homes—the confidence and skills in using technology that they will need after graduation.

> *I don't care what field they're in, be it factory worker, office worker, medicine or whatever.* [There is no place where technology will not be used.] *It's getting harder and harder to get jobs. You want your kids to get a leg up. It's becoming a necessary ingredient.* —Middle school principal

Researchers have argued that technology has the potential to dramatically change the way in which our schools are structured—serving as a catalyst for doing away with the division of instructional time into small blocks and discrete disciplines and to rethink the way we use physical classrooms and teaching resources (Collins, 1990; Newman, 1990). A number of our sites reported consciously deciding to use technology in order to advance their reform goals and to *support changes in school structure*. Many respondents shared the view that the use of technology would facilitate various aspects of their restructuring efforts, for example, by providing a context for increased collaboration among students or serving as a tool for project-based learning. Several district administrators expected technology to free up teacher time by taking over or supporting administrative and routine teaching tasks. The administrators setting up the teacher network, for example, expected it to lower boundaries between schools, districts, and even states.

For schools within TeacherNet and for the Maynard Computer Mini-School, the use of telecommunications to promote *greater access to outside resources* was a central underlying reason for the implementation of technology. Although this did not serve as an initial goal for technology use within other sites, the growth of the Internet and increased interest in its educational potential have made this a recently emerging goal for most of the schools in our study. At the time of our data collection, many sites were at various stages in planning for network installation and Internet access. Within these schools, educators spoke of telecommunications in terms of broadening students' information sources and bringing "the outside world" into the classroom.

Finally, in several cases, there were individuals who were simply intrigued by new technologies and wanted to explore what those technologies could do in an educational setting such as their own. Not surprisingly, the desire to *explore technology capabilities* was most likely to be a factor in cases where there was an external partner involved in the design, manufacture, or selling of technology products. Although we felt that technology push was one motivation for some implementations, in no case was it the sole motivation.

All sites began with an initial purpose or set of goals for the use of technology, but it comes as no surprise that these goals continued to evolve as participants became increasingly familiar with the capabilities of the technology once it was installed.

This section has addressed the issues that served as the original impetus for technology implementation within each of the nine sites. Chapter 8 of this report addresses the effects that teachers and administrators perceived their technology use to have—providing insights into the motivations that sustained and enhanced their involvement with technology.

Instigators for Change: A Systemic Perspective

Theoretically, at least, innovations and reform activities can start at any level of the education system—anywhere from the federal agency seeking to stimulate reform through new programs and policies related to funding to the individual classroom teacher who is inspired to do something in a different way. Exhibit 6 provides descriptions of some of the stronger examples of actions by different levels of the education system in support of technology-based reforms.

Our case studies provide information on the magnitude of the influence of various levels of the education system *from the perspective of the classroom and the school*. That is, rather than asking federal and state administrators what impact they had had on technology-supported reform efforts, we asked teachers and administrators about the factors that had shaped their efforts, probing for the influence of district, state, and federal policies. In brief, the influence of various levels of the education system was strongly and inversely correlated with distance from the classroom. Teachers, principals, and technology coordinators were typically the source of leadership for technology-supported reform efforts. Although less central, district actions, resources, and policies were very important also. We judged the district's role to have been important in stimulating nearly half of the innovations we studied. State policies and funding programs were important influences for just two of the sites. Federal policies and funding had some influence, but were not major factors for any of the implementations. External partners, such as technology manufacturers, foundations, and research institutions, were much more important. In the following sections, we describe in more detail the variety of roles and influences reported for each level of the education system.

Federal-Level Supports

The federal government influenced case study sites in two basic ways. One was *research*, which was conducted with federal funding in several cases. Two sites were greatly influenced by research projects conducted by university or research institute staff with funding from federal agencies. (Two other sites were greatly influenced by research projects funded by an equipment manufacturer.) Research projects brought not only resources, such as equipment and technical assistance, but also intellectual influences to the participating classrooms and schools. These programs brought an important source of ideas about how technology could support instruction, were instrumental in attracting resources in the form of equipment and funding, and provided counsel and technical support for teachers addressing the challenge of integrating technology into their practice. In addition to this firsthand participation in research, sites were also influenced by prior research, some of which was performed with federal funding.

Exhibit 6

Providing an Inspiration and Incentive for Change

School Level

Extensive use of technology within this urban elementary school began in 1986, when Alan Kay, a leading innovator in human-computer interaction research and development, approached the school about becoming a site for his research. The principal and teachers were interested because their educational approach stressed hands-on activities, and they thought that technology could be used to provide "mental bridges" between the physical, hands-on activity and symbolic knowledge. The principal felt strongly, however, that the introduction of technology had to be done on a whole-school basis, so that it would be a force for integrating rather than separating the teaching staff. In the first year, the school tried a computer lab, but subsequently the teachers voted against it because they did not like separating the students from their regular classrooms. With support from the researcher's company, the school eventually received enough computers to have one for every two students in all classrooms. The researcher and others from his company described and demonstrated new ideas and new technology for the school at after-school and intersession meetings over a period of 6 years. The company also provided technical support for teachers' development of their own technology-supported curriculum ideas.

District Level

Designing a New, Model School. When it became apparent that changing demographics in this "exurban" district would require reopening an old school, the superintendent sought to make it a model for educational uses of technology. He believes that technology will be a part of students' futures and can magnify teachers' capabilities. Given the demographic changes in the district, the new middle school would serve a widely diverse student body, but one in which the majority of students would be low-SES and from minority backgrounds. Originally, the superintendent put forward the concept of a magnet technology school, but the high-SES parents in other parts of the district preferred to keep their children closer to home. The superintendent proceeded, taking what was described as a "political risk" in "putting the money where it was needed most." The district refurbished the school, devoting $2.2 million to the installation of a schoolwide network and other technology. The new school's principal was hired a year in advance of the school's opening and given the charge of developing a "state-of-the-art" middle school that would integrate technology with instruction and provide effective educational programs for a disadvantaged population. Effective schools principles, such as high standards for all students, monitoring and feedback, and developing a safe environment and a campus leadership team, were considered equally important.

Promoting Technology as Part of Districtwide Reforms. The superintendent of this racially diverse urban school district is regarded as a strong leader and a major proponent of school reform. Technology has been a significant part of the district's school reform efforts. Members of the education community believe that technology motivates students, increases their self-esteem, and supports learning in a broad range of areas (e.g., writing, problem solving, mathematics). Moreover, they argue that technology will be essential to success as

Exhibit 6 (concluded)

citizens and workers in the 21st century; they feel a particular imperative to provide the low-SES students in their schools with the technology tools that more affluent communities take for granted. In 1992-93, the district began using its voluntary desegregation funds to support an ambitious districtwide school restructuring effort. Participating Demonstration Schools engage in self-reflection and assessment, choose an education model (e.g., the Comer model), and plan and implement schoolwide changes based on the assessment of needs and the selected model. The district has provided $300 to $400 per pupil per year to schools participating in the Demonstration Schools program. The district required participating schools to include a technology implementation plan, and in the first year recommended that 25% of the demonstration funds be spent on technology implementation (50% hardware, 25% software, 25% staff development). The district has provided technical assistance for technology implementations through a new district-level position for technology and curriculum. Subsequently, universities, corporations, and private foundations have approached the district seeking school partners in technology-related research. When the district set up competitions for schools that wanted to participate in these projects, the Demonstration Schools have typically had the leadership and staff capabilities as well as the technology infrastructure to take advantage of the new opportunities.

State Level

This large state has supported school implementations of technology in a number of ways. In addition to an early program of state support for teaching computer literacy and providing computers for teachers, there have been a series of state grants programs designed to support the integration of technology with school reform activities. Under one such program, schools were invited to apply for grants to support innovative ideas for using technology to support students' acquisition of thinking skills. Another program provided multiyear support for schools to develop, evaluate, and disseminate approaches to integrating technology within specific subject areas (e.g., science, language arts). This program complemented a model technology schools program that provided 5 years of funding to school districts setting up across-the-curriculum programs for technology implementation. In an innovative public-private partnership arrangement, the state has cofunded the development of multimedia programs that address the contents of state curriculum frameworks. The state department of education has made an effort also to conduct its other school reform activities in a way that is compatible with and supportive of technology implementations. The state's school restructuring grants program, for example, encouraged the use of technology as one tool for implementing school restructuring. The state's new curriculum frameworks and assessments involve the kinds of performances and higher-order skills that students might be acquiring through their work with technology.

The second federal influence was federal program *funding* that could be used to support technology-based innovations. More specifically, three of the case study sites used Chapter 1 and/or Chapter 2 money to purchase equipment or to support additional positions that made technology-based activities more feasible. In no case, however, was this federal funding sufficient to fund the majority of the hardware and software, let alone the teacher training and technical support, needed to launch a major innovation. Federal funds were important nevertheless in that they helped to sustain or support technology programs launched with other funds at several sites.

Unlike the federal influence through funding of research projects, the federal funding usable for technology-related activities came without a pedagogical framework. Although much has been written about the conservative influence of the Chapter 1 program's emphasis on testing basic skills, with the side effect of boosting sales of integrated learning systems (ILS) supporting drill and practice on these skills, our case study sites did not put a strong emphasis on drill-and-practice uses of technology.

State-Level Supports

At a gross level, reforms tend to get classified as "top down" or "bottom up." In the top-down approach, state agencies mandate a change that they believe will reform education, for example, by requiring that every student in the state receive a certain weekly minimum time in computer-based learning. Bottom-up approaches begin at the classroom or school level, where innovations may begin with or without state (or district) support or even awareness.

Much of the school reform rhetoric calls for giving those closest to students—i.e., schools—more decision-making authority in return for accountability. At the same time, however, there are calls for making education reform *systemic*, by coordinating all components of the system (e.g., curriculum, assessment, teacher training) to create a coherent set of educational experiences (Smith and O'Day, 1990) and for improving education through the adoption of higher *standards*. Both of these trends have stimulated greater state activism in education. California, for example, set out to implement a systemic reform approach through the development of curriculum frameworks with specific learning goals in seven areas, recommended instructional approaches, textbook adoptions based on the curriculum frameworks, and a new assessment system. Utah and Florida are among the states that have made major investments in technology as a tool for improving their schools. Ironically, states sometimes attempt to mandate bottom-up reforms. Texas and Kentucky, for example, *require* districts to implement site-based management.

The case for state-level planning and activity is bolstered in the area of technology implementation by the fact that states can both garner a greater set of technical resources and use leverage in equipment and software purchases and network usage fees that would be impossible for districts or individual schools to duplicate. The requirement for state-level or broader involvement is even stronger in efforts involving telecommunications, given the fact that broad access to resources and the sharing of information across school, district, state, and even national lines are essential activities. Higher levels of government also have an important role in guaranteeing equality of access to technology.

None of the case study implementations in our sample (spanning seven states) could be characterized as primarily a state-initiated, top-down program. States did influence many of the projects and provided important supports in several cases, however. In general, we found evidence of four kinds of state influence:

- Provision of a general reform philosophy and a mandate to experiment.
- Influences on content and pedagogy through curriculum frameworks and assessment programs.
- Provision of resources.
- Recognition of outstanding programs.

Several of the sites were active in state-sponsored grants programs and education initiatives. In some cases, state restructuring grants directly encouraged schools to incorporate the use of technology into their plans for reform. The state education agency for one of our schools enacted a curriculum framework that included computer literacy as one of its “essential elements.” This same state mandated that a minimum of $27 per student be spent on technology (although additional funds were not provided to cover the expense). One of our case study sites had received funds through a state program that supported school restructuring efforts. Another had state funding as a model technology site; a third applied for and received state charter school status. By instituting these programs, the state provided what Jane David (1991) has termed “an invitation to change,” without specifying the specific form that the innovation would take. For at least two of these schools, the existence of the state grants competition was pivotal in bringing teachers together to think through what they would like to do, and subsequently to carry out the funded activities. The grants program gave the teachers an authentic purpose for coming together and rethinking what they teach and how they teach it.

Many, but not all, of our case study sites evidenced considerable sensitivity to the contents of state curriculum frameworks or instructional objectives and of statewide testing programs. Those informants who talked about state curriculum frameworks or instructional objectives appeared comfortable with their contents; we did not hear stories about teachers implementing state-mandated curricula with which they felt at odds. At only one site, however, did the state’s curriculum framework have a major impact on the software and technology-based activities implemented by the school.

Similarly, our case study schools accepted state testing as a fact of life but did not let it drive their programs. In some cases, the state tests were clearly incompatible with the content of the school's core instructional program. Some sites argued that scores on standardized tests were therefore not good reflections of the strength of their programs and went ahead and taught what they felt was most appropriate for their students. Some sites coped with state tests by "giving them their due"—an intensive period of cramming right before the test or a part of the school day devoted to the kinds of basic skills emphasized by the test. In several of the states in which our sites were located, the states were moving toward more performance-based forms of assessment or the assessment of higher-order skills, and a number of teachers were involved in either state or local efforts to develop more authentic assessments that would be a better match for their instructional programs. Overall, testing was a general influence on the schools but did not appear to have specific impacts on the technology implementation per se, with the exception of one middle school where an ILS lab was set up with the explicit goal of using technology to make sure students acquired the kinds of basic reading and math skills measured by standardized tests.

In addition to the funding for school restructuring and technology programs described above, states provided some more specific resources that affected schools' use of technology. One site was able to become active in telecommunications-based activities because of the state's development of a statewide network to link schools to the state universities and the Internet. Another state supported the participation of rural schools in a teacher networking project by providing reduced-cost dial-up access to the Internet. A third state supported one of our case study schools by funding the development of customized intelligent software for the school to use in developing and documenting individual instructional goals for its students.

Finally, state recognition of several sites as exemplary schools brought distinguished visitors and media attention. Although this kind of attention has its costs, it can help to build student and community pride in the school. Case study sites found also that positive publicity gave them clout when seeking district waivers or support.

District Roles

Districts were much more influential than states in shaping the school reform technology implementations we studied. We describe district roles in two phases of technology-supported education reform: first in the initial instigation of the innovation and then in its ongoing support.

Initiating Reforms—With respect to the initiation of the innovations we studied, districts could be characterized as playing one of three roles: initial planner, opportunity broker, or spectator.

In three of our nine case studies, districts were at the center of *initial planning*, conceiving the original idea and providing funds for the innovation. In the case of TeacherNet, school superintendents set up and funded the network for communicating and sharing resources. South Creek and the School of the Future were both conceived at the district level as embodiments of innovative structures, ideas about more effective instructional practices, and exemplary use of technology for middle school students. Although in both cases the original impetus, the required extra funding, and needed waivers came from the district, leadership devolved to the school staff relatively quickly.

A less pivotal but still important role played by the district for four sites was that of *opportunity broker*. The main leadership for these initiatives came from within the school, but the district gave the school opportunities for outside funding and partnerships. In these cases, the district became aware of external funds available for schools willing to participate in various kinds of restructuring or technology implementation activities, and district staff put them in touch with schools in our case study sample. Nathaniel Elementary is an example of a school benefiting from this kind of district involvement. As university researchers and foundation-funded programs contacted the district seeking schools serving economically disadvantaged students with a strong staff willing to try innovations, the district directed them to this school because it had leadership and a staff prepared to take advantage of such opportunities. As Nathaniel's principal described it, "A lot of opportunities came our way because they knew that we would do something with it."

Bay Vista's district had the explicit goal of building technology capacity and looked for a school with a staff that could participate in seeking funds for and implementing projects involving technology use. John Wesley obtained the opportunity for a long-term grant from a foundation after the district superintendent met with the CEO of the foundation's parent corporation at a Business Roundtable meeting. In these cases, the district's role was more one of brokering opportunities than of shaping the innovation per se. School leadership, in the form of a supportive principal and a core teacher group, was decisive not only in taking advantage of the proffered opportunity but also in determining exactly what form the innovation would take.

Finally, for two of our case study sites the district's role can be characterized as that of *benevolent spectator*. The opportunity for the Progressive School to obtain a major infusion of technology and to work with Alan Kay and Apple-funded technical support staff on instructional uses of technology came directly to the school because of its own unique character and reputation. At Maynard Computer Mini-School, it was the computer coordinator who made connections with university-based research programs that resulted in the receipt of grant funds to set up and operate the computer network. In both cases, however, the district's spectator role during the initiation of the innovation evolved into somewhat more proactive involvement as the district learned and benefited from the school's example. Moreover, strong school leaders for technology innovations were quick to see that the favorable publicity their programs generated for the district could be leveraged into clout in advocating for resources.

Potentially, districts can play a major role in moving successful innovations beyond single schools to more widespread adoption. Maynard Computer Mini-School's district perceived the value of trying to disseminate the school's model for using networked computers to other schools within the district. However, dissemination has not proceeded very far. From our observations, many districts do not put adequate resources into this role—they point to model technology-using sites with pride, but few develop plans or commit significant resources for dissemination.

Ongoing Support—In addition to the instrumental roles in conceptualizing innovations or brokering opportunities described above, districts provided a range of support services and resources.

Outside funding is critical for the majority of technology-supported innovations, and districts frequently have resources that schools lack for pursuing these opportunities. Thus, *support for grant writing* is an important district role. The district can not only act as the fiscal agent for grants but also provide help from staff who are experienced in writing grant proposals and familiar with the process.

District *bargaining and purchasing power* for obtaining equipment, site licenses, telecommunications services, and so on, was another important contribution from the perspective of our case study schools. Even in those of our case study sites where the districts did not provide major funding or equipment for an innovation, they often supported the program with equipment, power, wiring, security systems, maintenance, or additional space. District support for maintenance was singled out as an important support at a number of sites. Even though teachers or technology coordinators at a number of schools became adept at routine maintenance (at three sites, they even earned repair licenses), more serious problems require professional services, and districts can offer or contract for these in a more cost-effective manner.

Although *technical assistance* on technology is an important district function generally because districts are likely to have a technology coordinator in cases where individual schools do not, such support appeared less than critical for the particular sites we studied. To be effective, technical support needs to be readily available on-site, and most of the case study sites found a way to provide this, in some cases through a district-funded position, but often through external funding or teachers' initiatives to train themselves. In addition, because we selected sites with a reputation for successful technology implementation, they were typically ahead of other schools in their districts in technology use, and many felt they had little to learn from district-provided technical support.

Finally, innovating schools are likely to want to hire individuals with special qualifications or to desire different allocations of space and time than specified in district formulas. Districts have an important role in *granting waivers* and in *protecting reforming schools* from detractors who oppose deviations from the status quo. When the teachers forming Maynard's computer mini-school, for example, voted to give up the daily preparation periods provided for in their contracts in order to obtain smaller classes, the union local threatened to sue. The district administration intervened, using its political clout with higher levels of the union to dissuade the locals from following through.

District-Level Impediments—Our cases illustrate the positive roles that the district can play in instigating or complementing reform activities. At the same time, it should be noted that in some instances we found evidence of the ineffectiveness of district attempts at top-down decision-making with respect to restructuring and technology implementation. Decisions regarding instructional approaches or technology made at the district level without the involvement and "buy-in" of the teachers who were expected to implement them sometimes backfired, resulting in wasted resources and resentment. In several cases, long-standing district policies worked at cross-purposes with the district's own reform efforts. Exhibit 7 provides descriptions of some of these difficulties, along with some of the solutions and negotiations that emerged. Lack of initial and ongoing communication between district and school, a change in leadership at the district level, and lack of follow-up support on the part of the district were three of the obstacles related to the district's role in initiating and sustaining reform. At both East City High School and the School of the Future, for example, district support was diminished with the loss of superintendents who had been instrumental in getting the projects off the ground.

Another frustration cited in several cases was red tape concerning software selection and purchases. Schools with technology-savvy staff get very frustrated when the district limits the equipment or software they are allowed to buy (or, more typically, just makes it very cumbersome to obtain things that are not on the "approved" list).

Exhibit 7

Limitations of Top-Down Technology Implementations

Top-Down Selection of Equipment

When teachers are not involved in selecting technology and do not see the connection between its capabilities and what they are trying to accomplish, the technology is likely to be either ignored or used in ineffectual ways. John Wesley Elementary School's district gave every school a satellite dish. The school had not asked for the dish and rarely used it.

In part because of state and district policies regarding teacher qualifications and hiring, the lead staff at the School of the Future was not brought on board until 6 weeks before the school opened. Consequently, major decisions regarding technology selection were made by district administration without the benefit of teacher involvement. One of the major purchases, a large integrated learning system (ILS) lab and extensive software, represented a kind of drill-and-practice approach to acquiring basic skills that was not compatible with the instructional philosophies of the subsequently hired staff. Although student time in the ILS lab was scheduled, most of the teachers took little interest in it, and student lab work was conducted in isolation from other classroom activities. Falling scores on standardized tests later called teachers' attention to the issue, and a greater effort was made to integrate ILS with other aspects of the curriculum in more meaningful ways. The general view of the teaching staff, however, was that the lab represented a mismatch with their overall program.

Modifying District Restrictions on School-Level Technology Planning

Nathaniel Elementary's school district has made a major commitment to districtwide reform through its Demonstration School program. In the first year of the program, the district took a somewhat top-down approach to shaping the restructuring process. Participating schools were required to follow one of three district-approved education models and to allocate 25% of the project funds to technology. Schools were asked to make their technology selections after careful planning and reflection, based on their stated instructional approaches and long-term goals. However, long-standing policies regarding purchasing schedules forced schools to make their selections while still in the early stages of the planning process. The district is in the process of revising these policies to accommodate a more gradual approach to hardware and software procurement. In addition, the district has been responsive to the need for schools to have greater flexibility in choosing the model on which they will base their restructuring efforts. In some cases, demonstration schools are creating their own education models. The district has also loosened the restrictions regarding the percentage of funds to be spent on technology, leaving this to the discretion of the schools. At the same time, the district is providing support to school administrators and teachers with in-services, visitations, and ongoing feedback to aid their planning and implementation process.

There were also instances in which schools felt that long-standing district policies or practices having nothing to do with technology per se impeded their progress. Many of these instances had to do with staff allocation and hiring practices. Innovating schools are seeking to rethink roles within the school and to reassign roles in ways that free up resources for new essential activities. In some cases, rightly or wrongly, districts have been more cautious about innovating. One school reported that the district delayed its plan to replace the assistant principal position with a half-time project coordinator and half-time parent liaison for many months. Another had difficulty obtaining waivers to hire staff without the standard teaching credential. One school was unable to get approval for its plan to do away with the principal’s position altogether and had a half-time principal thrust on it.

School Leadership

Although districts played an important role in shaping or supporting reforms at most of our sites and three of the innovations certainly never would have existed without district leadership, the most important leadership in almost every case was at the school level. Schools developed cadres of teachers active in designing and implementing innovations. The school principal appeared to be pivotal in inspiring and coordinating these activities at roughly half of the sites. In other cases, a technology or project coordinator emerged from the teacher ranks to play this role.

Even when the principal was not an active intellectual leader or manager for the innovations, sites maintained that support from the principal was an important factor. In cases where the principal was not a strong supporter, there was less success in getting the innovations spread throughout the school.

One of the leadership roles that was key to the reform efforts at a number of sites was that of program advocate and liaison to the district. In several cases, it was the principal who fulfilled this role; in a few cases, it was the technology coordinator. In each case, an important bridge between school and district was established by having an individual who was adept at articulating the goals and the needs of her or his program to key district players and whose leadership and professionalism were recognized at the district level. These characteristics place an individual in a unique position for providing the school with positive visibility and for garnering resources and support from the district and the greater community. The principal at South Creek viewed this aspect of her role as critical to the success of her program:

> *You must have someone out there to fight for the program, who is able to get the funding, deal with all the people, and knock down barriers.   The only thing I*

> *want to say about that is if you don't have someone doing that, then the program becomes a second-, third-, or fourth-class citizen. It will be relegated to that role.*

But even more important, we believe, is the school leader's role in making the technology-supported reform a truly schoolwide effort. It is one thing to use technology in isolated classrooms and quite another to make technology a potent force in transforming an entire school. Although schools that choose to make technology part of their reform strategies face important challenges with respect to physical infrastructure, funding, equity, and ongoing maintenance, our case studies suggest that the greatest difference between more and less successful technology implementations resides in their artfulness in creating a coherent *schoolwide* approach to using technology in the core curricula for all students. (Chapter 5 provided a discussion of strategies for stimulating a schoolwide vision and the involvement of a majority of teachers.)

Outside Influences: External Partners and the Role of Research

In recent years, entities outside the education system, notably the business community, have been active players in efforts for school reform. Nearly every one of our case study sites had one or more partnerships with an external entity. The three major types of external partners were (1) corporate, (2) foundation, and (3) university research groups.

Corporate Partners

Corporate donations and partnerships played a facilitative role in the implementation of technology at most of the schools featured in this study. Support ranged from extended equipment loans to full-scale technology installation and technical support. Seven of the sites received significant hardware and software donations, in six cases from equipment manufacturers or software developers. Computer manufacturers and software developers see schools as an important market, and they are eager to have schools using their products in exemplary ways so that they can point to success stories in their marketing. Apple Computer in particular provided several schools not just with hardware and software but with an extensive support infrastructure in the form of on-site technical support and teacher professional development opportunities. Another site's computer network activities will be supported by a telephone company in the coming year, through a grant to a nearby university. Although donations of various types of hardware and software may be harder to come by as the schools' use of these technologies becomes more commonplace, there appears to be plenty of opportunity at present, particularly with companies producing products connected to the use of wide area networks.

In addition to the major donations from corporations that produce hardware or software, there were a few mentions of smaller-scale support from local businesses. In several cases, companies gave small grants to support creative technology-based projects designed by individual teachers; for example, an industrial arts teacher received support for a project using computer drafting tools to produce wooden replicas of dinosaur skeletons. Local cable news stations have donated services at several sites, providing students with hands-on experiences with video production. At another site, a pair of companies and a local mall instituted a project involving students in the design and running of a small business. A teacher at the case study school developed computer-supported classroom activities around this project. Business partners played a more visible role in the establishment of TeacherNet. The network has 10 corporate partners who helped to develop the network's strategic plan. Local business partners have served on school technology committees, often bringing a valuable level of technical knowledge and expertise.

Schools serve as an important testbed for new hardware and software, and several corporations provided teachers at case study sites with the opportunity to help shape the development of educational products through their critical feedback. A number of teachers commented that this experience gave them a renewed sense of professionalism. Several stated that this was one of the few contexts in which they felt recognized and appreciated for their expertise. An obvious trade-off is that extra time is required on the part of the teacher. At the Progressive School, Apple dealt with this issue by compensating the teachers for their consulting services. This was an unusual arrangement; at other sites corporate partnerships provided teachers with opportunities to participate in specialized training and conferences. One downside of serving as a testbed for hardware and software as it is being developed is that new systems are often more prone to difficulties and must constantly be updated. As one seasoned teacher at a testbed site quipped: "When you pilot new programs, expect there to be glitches. Otherwise, they wouldn't be giving you all that equipment!" For most teachers, the positive aspects of serving as a testbed outweighed the negative.

Given their interest in marketing and in drawing attention to successful uses of their products, corporate partners have served as important vehicles of dissemination for schools that otherwise might never have had their stories told. After providing the video equipment for the Kid Witness News program at Maynard, Panasonic brought high visibility to the project and the school. At the same site, a separate corporate grant funded the technology coordinator's production of a guide on technology use in education. At East City High School and the Progressive School, Apple has provided several avenues for dissemination through supporting teacher travel to present at conferences, installing network communications among various project sites, and funding the production of videotapes featuring student uses of technology.

An important issue for schools that depend heavily on corporate-sponsored technical support is how to wean themselves and achieve independence once this support is reduced or has ended. The Progressive School was in the midst of facing this challenge at the time of our site visit (see Exhibit 8).

Exhibit 8

Becoming Technologically Self-Sufficient

After 7 years of extensive technical and financial support, Apple began stepping down from its role as corporate benefactor for the Progressive School, ending the provision of on-site technology staff and reducing the amount of funds going into the project. After some initial anxiety, the response of the administration and teachers was one of deep appreciation for the support they had received in the past, and acknowledgment of the fact that independence is an important step in the school's growth. Most teachers had acquired sophisticated technical skills through their participation in the project, fully integrating the use of technology as a tool throughout the curriculum and having developed their own computer-based learning activities (e.g., teacher-developed *HyperCard* writing and music programs, simulations). The principal reflected that the staff had received "7 years of a fabulous education from Apple..." In preparation for taking over all aspects of technology use, six teachers were trained by Apple in computer maintenance. One of the biggest challenges for the school will be finding a way to cover the cost of maintaining and upgrading the equipment. In retrospect, the principal felt that one of the downsides of their dependence on Apple was the fact that there were many hidden costs that are only now being taken into account as the school staff consider what it will take to run things on their own. She recommends that schools and corporations work together to make these costs explicit early on, so that a realistic plan for eventual independence can be developed.

Foundation Partners

A second major type of external support came from foundations (which are in turn the recipients of funds from their founding corporations). Four of our case study sites received significant foundation funding. At John Wesley, a foundation-supported program supporting multiple schools in this area in implementing thematic instruction in science was instrumental in involving the school's teachers in an across-the-board effort to revitalize their school. A grant from a second foundation for school restructuring activities led to the creation of a Curriculum Action Team, which was the impetus behind the effort to bring technology resources to bear in their efforts to teach their low-income, largely limited-English student body more effectively.

This grant had a dramatic impact on the reform activities at John Wesley, through a large investment in training as well as evaluation. Two criteria for participation were that the school practice site-based management and that at least one-third of the teachers actively be involved in restructuring activities.

Nathaniel Elementary participates in the GALAXY pilot project of the Galaxy Education Institute, a foundation funded primarily by Hughes Aircraft. At another site, a local foundation funded the evaluation of the school's innovation. TeacherNet received foundation funding for developing its telecommunication system and for a health education curriculum that was distributed over the network.

Although foundation funding has been an important positive influence at many schools, one principal lamented what she sees as an "only new activities" mentality. Foundations prefer to fund innovations, making it difficult to find support for ongoing projects outside the realm of basic activities supported through general education funds. This tendency was graphically illustrated at one of the case study sites that had a school garden, which was used for ecology-related projects in which students recorded data (e.g., on plant heights) that was shared with other schools over the network. The school was unsuccessful in obtaining outside funds to continue activities with the existing garden but did receive foundation support for planting a new garden!

University Partners

Although some of our sites were influenced or supported by relationships with university partners or research teams, in no case was there systematic involvement of a teacher education program in helping a site to institute or support a technology innovation. Where partnerships did occur, they were more likely to involve an individual faculty researcher who used the school as a research site or involved teachers in a program of inquiry. The CSILE activities at Nathaniel Elementary, for example, involved software designed by researchers at the Ontario Institute for Studies in Education. The design of Maynard Computer Mini-School's computer network was carried out in conjunction with Denis Newman's Earth Lab project (begun while Newman was at Bank Street College). A nearby state university did evaluation and other research studies on the East City High School computer mini-school program.

Influence of Research

Involvement in university research projects was very important for both Maynard Computer Mini-School and Nathaniel Elementary School. These programs brought an important source of ideas about how technology could support instruction, were instrumental in attracting resources in the form of equipment and funding, and provided counsel and technical support for teachers as they addressed the challenge of integrating technology into their practice.

Beyond such actual involvement in research, there were research influences on many of the case study sites. In establishing South Creek Middle School, both the district superintendent and the principal looked to the effective schools research for good practice concepts. This review led to practices such as site-based management teams, the institutionalization of self-studies, and the collection of school climate data. The principal also did an intensive study of the literature on technology and instruction during the year before the school's opening. This review led to the school's emphasis on software tools rather than didactic uses of technology.

Jerome Bruner's theory and research was one of the original inspirations for the Progressive School, which continues to work to provide a spiral curriculum in which the same powerful concepts get taught and retaught at increasing levels of sophistication as students advance developmentally. The school's involvement with the human-computer interaction research of Alan Kay was another important influence as Kay worked with the teachers over a period of years, both in conjunction with his Vivarium research project and as a general support to their thinking about what technology could contribute to their teaching.

Information processing research and Howard Gardner's theory of multiple intelligences were clearly major influences on the handbook for integrated thematic instruction (written by Susan Kovalik and Karen Olsen) used in the science improvement program in which John Wesley participated. In several schools, principals were active consumers of educational research and viewed it as part of their role to share current and applicable research with their staff.

8. TECHNOLOGY SUPPORTS FOR PROJECT-BASED LEARNING

In the introduction to this report, we presented a reform-oriented model of constructivist learning. Authentic, challenging tasks embedded in long-term projects were at the heart of that model. We argued that centering instruction around meaningful tasks would create pressure for the other kinds of reforms that educational researchers advocate—specifically, for collaborative learning, heterogeneous groupings of students, teachers acting as facilitators rather than lecturers, multidisciplinary curricula, longer blocks of time, and more authentic forms of assessment.

Our premise in designing this study—in selecting our schools and sample classrooms and in developing our observation and interview protocols—was that technology could provide significant supports for the implementation of this particular model of constructivist learning. In this chapter, we examine the evidence for that hypothesis.

Ways in Which Technology Supports the Model

Authentic, Challenging Tasks—Both observational and interview data from our case studies provide confirming evidence for the proposition that technology is an important enabler for classes organized around complex, authentic tasks. When technology is used in support of challenging projects, it in turn can contribute to students' sense of authenticity and to the "real-life" quality of the task at hand. As one teacher put it, students need to feel that they are "using real tools for real purposes." Being able to access the tools that are used by professionals for similar tasks allows students to aspire to a level of work and quality of product that more closely reflect what they see and know of the outside world. Bay Vista students, for example, used *HyperStudio* to create multimedia reports that included not only text but also digitized photographs and sounds as well as artwork. At the School of the Future, students in an architecture and design class used computer-aided design programs to plan and design a home for a hypothetical family with specified needs and financial resources.

By the upper elementary grades, students evidenced an awareness of the standing of the technology they were using with respect to a professional community of practice and a preference for working with the same hardware and software tools as professionals:

> *The kind of musical* [technology] *that we have here is the stuff that professional musicians dream of . . . . They're wishing they had this kind of technology. It costs literally thousands of dollars.* —Fifth-grade student

> *We should be able to learn to use* [commercial technology] *more, because if we learn how to use it, it is going to be as easy as the school equipment, and it will be higher technology. You'll be able to do more, do more things, and be more flexible.* —Fourth-grade student

Bringing the outside world into the classroom through the use of telecommunications adds another dimension of authenticity to schoolwork as students are able to link with real people and places, as well as public databases (e.g., NASA, NOAA), as information sources. Maynard Computer Mini-School students, for example, experienced an increased sense of communication with external communities not only by obtaining information from external sources but also by creating documents describing school activities for their Gopher server and their own World Wide Web home page:

> *It only takes a little mouse. Click on that and you've got the whole world on the computer.* —Fifth-grade student

Exhibit 9 provides three examples of challenging, authentic projects supported by technology.

Our emphasis on the way that technology can enhance the authenticity of classroom projects is not meant to imply that using technology will *necessarily* make a classroom assignment authentic. Authenticity lies more in the goals and content of the activity, as designed by the teacher, than in the use of technology. Our observations across sites gave us the opportunity to contrast skills learning and technology use in isolation with the exercise of the same skills in the context of meaningful projects. Tasks that were grounded in activities that were challenging and made sense to students had a positive impact on their motivation, understanding, and achievement. For example, fifth-graders working on the Multicultural Heroes project at John Wesley (described in Exhibit 9) used word processing to write a series of letters to local businesses requesting donations of goods and services (e.g., camera microphones, printing) and/or participation (e.g., allowing themselves to be interviewed). As they wrote at the computers in pairs, students engaged in lively discussions regarding both the form and content of the letters, seeking out one another's input and revising as they went. They put careful thought into how much and what kind of information to include (e.g., "We have to tell them who we are...") as well as how to present their requests in the most compelling fashion. The activity continued over multiple sessions across several days, culminating in the printing and the actual mailing of the letters. In contrast, at another site, middle school students participated in a 50-minute word processing class that during one class period focused on the writing of business letters. The teacher instructed the students to "just make up" the content (e.g., a request or a complaint to a fictitious business), placing the emphasis of her instruction and feedback on proper formatting and on the mechanics of using a word processor. Many students were at a loss for what to write

Exhibit 9

Examples of Authentic Activities Supported by Technology

Multicultural Heroes Project

In a fifth-grade bilingual class at John Wesley, students engaged in a year-long project in which they developed multimedia descriptions of the lives of minority group members who had achieved prominence within the students' local community. The project was motivated by the lack of curriculum materials focusing on Latino role models written at a level appropriate for students just transitioning to using English in the classroom. The project involved identifying local Latino, African-American, and Vietnamese leaders (including politicians, businessmen, researchers, and educators), conducting and videotaping interviews, and composing written highlights from the interviews. Technology made it possible for students to aspire to producing, and making many copies of, multimedia materials with a quality of appearance that would tempt others to purchase them.

The City Building Project

Each year, students in this mixed-age (8 to 10) team-taught class spend a good part of their year on a project designing a city of the future for the urban area in which their school is located. Students divide into neighborhood groups that must work together to decide what will be built in their area of the city. Each child is responsible for an individual parcel within the neighborhood. Students also have membership in city commissions (e.g., Environment, Building and Safety), which may pass regulations that apply to all of the neighborhoods. In the case of a controversial issue (e.g., treatment of the infirm elderly), students may develop a survey and administer it to their classmates to determine public opinion.

With one computer for every two students in the class, students are able to use technology when they feel it would support their assigned tasks. Students use word processing software in writing their city plans and descriptions. A drawing program (*Canvas*) is used when they need to design objects and buildings. *HyperCard* stacks and animations are used to illustrate the work of the various city commissions and neighborhood groups. Spreadsheet software is useful when it is time to calculate the effect of a decision under consideration on some variable (e.g., the effect of a building height limit on the number of residents that can be accommodated) and to graph survey responses. A portion of the city-building activities were videotaped and edited to produce *QuickTime* clips for a multimedia record of the project.

A Student-Run Manufacturing Company

Students in this middle school industrial arts class form companies and produce products such as wine racks, cabinets, or folding wooden stools for sale. Students elect company officials and divide into work teams to enact the various operations of a company. Many of the team activities are supported by technology. For example, the Finance Team uses

Exhibit 9 (concluded)

computer spreadsheets to find the lowest-cost materials and to create financial statements for the company. The Research Team uses drafting software in drawing up design plans. The Marketing Team uses the word processor in creating advertisements and product descriptions. A videocamera is used in creating commercials for the product; the commercials are then aired over the school's broadcast system. Most products require use of a computer-controlled lathe or mill. Final production is conducted assembly-line fashion, with the parts laid out in specific locations and some students acting out the parts of robotic arms to place the parts on the line. Products are sold within the school community. Students buy and sell stock in the company, and after the products are sold, stockholders get their share of the profits.

as they struggled with the task of generating content in the absence of a meaningful context. Some students were visibly bored by the activity, and there was little discussion between students regarding their work.

Longer Blocks of Time—Project-based work generally extends over more days and requires more time in a single day than do more traditional lecture, textbook, or worksheet-based classroom activities. Our observations in classrooms at the case study sites would suggest that when projects are supported by technology, there is even greater pressure for extending the time devoted to a given project or unit of study. Several teachers remarked that once they started using technology in their classrooms they had to increase the length of their rotations. Moving onto computers, pulling up the appropriate files, and accomplishing significant work takes time, and teachers found themselves restructuring the way they use time in the classroom to make it possible.

Another way in which technology use tends to lengthen the amount of time devoted to a given project is the ready availability of a convenient electronic record of prior work. When students have their own folders on a computer, they can easily go back to their work and revise it or amplify it. The pride they take in their technology-based work appears to increase the likelihood that they will revisit it and the capabilities that technology affords for easy modification of one's prior work support the inclination to revise and refine.

Multidisciplinary Student Exploration—In the course of our classroom observations, we saw many multidisciplinary projects. At the School of the Future, for example, middle school students combined art, mathematics, and social studies activities in the course of designing, analyzing, and developing plans for homes for hypothetical families with specified needs and limitations on income. Third- and fourth-graders at the Progressive School take part in a year-long project in which they design a "city of the future" for their metropolitan area (see Exhibit 9). Their science, mathematics, language arts, social studies, and visual arts instruction are all interwoven and embedded in city-building activities.

The Progressive School, School of the Future, John Wesley, and East City High School ACOT program all had explicit policies of designing multidisciplinary courses. Other schools implemented multidisciplinary, thematic instruction more on a project or class-by-class basis, but such activities were still common at our case study sites. [5]

We would be hard-pressed to say that the use of technology *prompted* this interdisciplinary approach; it seems that the multidisciplinary aspect of these activities was more a by-product of the authenticity and complexity of the tasks (real-world tasks do not come in discrete academic subject matter categories) rather than of the fact that technology was used. The city-building project, for example, existed as a multidisciplinary curriculum prior to the teachers' incorporation of technology into project activities. In contrast, the home planning project at the School of the Future was more directly inspired by a piece of software dealing with multiple aspects of home planning and design. In either case, the use of real technology tools supports a level of task authenticity and complexity that is strongly correlated with multidisciplinary work.

Changed Roles for Students and Teachers—When students are using technology as a tool or a support for communicating with others, they are in an active role rather than the passive role of recipient of information transmitted by a teacher, textbook, or broadcast. The student is actively making choices about how to generate, obtain, manipulate, or display information. Technology use allows many more students to be actively thinking about information, making choices, and executing skills than is typical in teacher-led lessons. Each child can be involved in independent or small-group work with the technology. Moreover, when technology is used as a tool to support students in performing authentic tasks, the students are in the position of defining their goals, making design decisions, and evaluating their progress.

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5. Multidisciplinary tasks appear to be more readily adapted at the elementary school level, where there is typically greater flexibility in scheduling and a single teacher or pair of teachers (in cases of team teaching) is responsible for implementing the curriculum across most subject areas. An interdisciplinary approach becomes a greater challenge at the middle and secondary school levels, where different teachers are responsible for teaching different subject areas and the schedule is more divided along these lines. In the latter case, it is necessary to build in time for teachers to meet and plan multidisciplinary projects. One option is to have students work on different aspects of the project in their various classes. Another is to alter the schedule, allowing for large blocks of co-taught project time.

The teacher's role changes as well. The teacher is no longer the center of attention as the dispenser of information, but rather plays the role of facilitator, setting project goals and providing guidelines and resources, moving from student to student or group to group, providing suggestions and support for student activity. The majority of classroom time may be devoted to independent and collaborative projects. As students work on their technology-supported products, the teacher moves through the room, looking over shoulders, asking about the reasons for various design choices, and suggesting resources that might be used. Such changes were reflected in teachers' reports that technology use increased the amount of collaboration, students' regulation of their own learning, and students' teaching teachers, (to be discussed in the next chapter).

Across the case study sites, there were numerous reports that technology had a significant impact on both teacher and student roles:

> *I truly think that technology has forced us to rethink the way we relate to kids in the classroom. It changes kids' roles so that they become more active and provides them with more kinds of exciting activities, which in essence become more challenging.* —Middle school teacher

> *I was definitely a sage on the stage when I started and taught math for 12 years, and I was the center of the curriculum and the center of learning, I thought. And as soon as I got computers, I found out, you know, I really don't need to be up there showing them everything. There's a lot of things they can learn on their own. In fact, they're better at learning things on their own and discovering things.* —High school teacher

Teachers who make extensive use of cooperative learning and project-based work develop skills as intellectual "coaches" and undertake a new role as the activity designer and facilitator rather than the chief "doer" or center of attention. Their role is by no means a passive one, however (Means and Olson, 1994), as illustrated by the example in Exhibit 10.

Project-based work and cooperative learning approaches prompt this change in roles, whether technology is used or not. However, technology use is highly compatible with this new teacher role. Several teachers reported that technology led them to give their students more control after they witnessed what students were able to do with technology and how they were willing and able to take responsibility for teaching themselves and one another. Technology facilitates a change in the teacher's role also by making it easier to act as a diagnostician and coach for the cognitive aspects of task performance. Technology can help to make the students' thinking processes more visible to the teacher, something that does not happen when students simply turn in a completed assignment for checking and grading. As teachers observe their students working with computer

Exhibit 10

Teacher as Facilitator of Technology-Supported Projects

During one of our observation periods, Mr. G., the teacher of the fifth-grade bilingual class engaged in the Multicultural Heroes project, initially worked with a group of students reviewing the videotape of an early interview. Encouraging students to reflect on the adequacy of the questions they had asked, he got them to think about their interview from the perspective of what an audience would want to know (e.g., "She said that she dropped out of school. What more would someone want to know about that?"). Next, he moved to a group practicing their interviewing technique using each other as mock subjects and supported their role play, helping them learn how to serve as helpful critics for each other's performance. Intermittently, he helped students with their use of the computer for transcribing key portions of completed interviews.

applications, they can see the choices each student is making, stop and ask about the student's goals, and make suggestions for revisions or different strategies. It is easier also for the teacher to take momentary control of the computer to demonstrate what is meant.

Moreover, technology often puts teachers in the role of learner alongside their students. This is a big change from the traditional role of the teacher as the one with all the knowledge and right answers. Instead, students are given the chance to see their teachers struggle with the acquisition of a new set of skills. Teachers who are not threatened by this change in roles report that the experience sensitizes them to the learning process in unexpected ways, giving them new insights into their students as learners. Engaging in the process of exploring technology with their students further provides teachers with an opportunity to demonstrate aspects of problem solving and learning that are rarely made visible in more product-oriented classrooms.

In addition to helping the teacher with technology, students also support the teacher by providing help to their peers. Students who are technology savvy are usually eager to share their knowledge with others. In our observations of technology-using classrooms, we saw numerous examples of students acting as peer coaches for each other, offering advice when a peer had trouble achieving a desired result with the software. Such advice giving was continual when students worked together in small groups, but was quite common also among students working individually on computers. Student coaching roles were generally not something that teachers had set up in any formal way, rather they emerged naturally as part of the parallel technology-based activity in the classroom. Several teachers remarked that the technology stimulated much more advice seeking and giving among students and that this propensity toward collaboration carried over into non-technology-based activities:

> *It's a much more facilitating atmosphere because kids help each other so much on the computer. It changes the style and tone of the classroom a lot.* — Elementary school teacher

Collaborative Work—Our classroom observations and teacher interviews identified many technology-supported projects in which students worked in teams. In the industrial arts class at South Creek Middle School, for example, students work with technology in teams that set up a company to design, produce, and sell a product (see Exhibit 9). The Research Team uses drafting software to draw the product designs. The Finance Team uses computer spreadsheets to identify the least expensive source of materials and to create financial statements for the company. The Marketing Team creates product descriptions and advertisements using the word processor. The instructor believes that participation in this kind of teamwork is a critical aspect of preparing students for the workplace because "this is what industry is moving towards."

The Computer-Supported Intentional Learning Environments (CSILE) system used in classrooms at Nathaniel Elementary was designed to support knowledge building through student collaboration in developing and discussing curriculum knowledge. The CSILE software supports students entering their ideas in "notes" and responding to each other's ideas in "comments." Notes and associated comments are linked and disseminated. Students think about arguments made by others and contribute their own ideas. Over time, they learn to cite other students' entries in the process of making their own arguments. As described in the next chapter in Exhibit 12, this technology supported the Archeological Dig Project, in which students were assigned to cooperative groups with responsibility for working on different aspects of the culture for a hypothetical society constructed by the class. Student groups used CSILE to exchange electronic notes with other groups, disseminating their ideas and making sure that the work being produced by the various groups was logically compatible.

Beyond this collaborative software and the larger projects expressly designed for execution by groups such as those described in Exhibit 12, we observed many classrooms in which students wrote collaboratively at the computer in pairs or small groups. The public display of text, the legibility of print, the use of the keyboard as an input device, and the ability to print out multiple copies are some of the capabilities that appear to support collaborative writing at the computer. Working collaboratively, students could subdivide the complex task of composing, allowing individual students to concentrate on one aspect or another and supporting the creation of a better product than a single student could produce alone. Often, one student would concentrate on producing ideas while another did the actual input. In other cases, one student would generate ideas and do keyboard entry while another student or several reviewed the ideas, offered suggestions, and pointed out needed corrections in writing mechanics.

Teachers reported that technology-based tasks can be excellent vehicles for prompting sustained interaction among students. In a fourth-grade class in which native Spanish speakers were transitioning to the use of English, the teacher reported that some students felt more comfortable working in English when they could work in pairs at the computer. We observed two students in this class working their way through a piece of tutorial software, which was written in English. They took turns reading entries, correcting and assisting each other with the more difficult words. They discussed the multiple-choice questions posed by the software and jointly arrived at choices before entering them. The teacher reported that some students who would not speak to her in English would work with an English-language program and speak English with a peer tutor. Several teachers at different sites with local or wide area networks reported that the ability to communicate over a network opened the door to exchanges between students who otherwise might never engage in dialogue. The barriers sometimes associated with differences in age, grade level, gender, and ethnicity appear to be diminished in this context.

Another way in which technology can support collaboration is by providing a record of interactions, which can be used for student and teacher reflection on process skills. The CSILE teachers at Nathaniel used "dribble files" of student CSILE entries in lessons addressing collaboration.

> *We did mini-lessons on what was a helpful, thoughtful comment.... Then we had the data to look at and analyze and ask, "What did this tell us? Did it further the dialogue?" It helped us continue to support the dialogue on a higher level.* — Elementary school teacher in CSILE classroom

Video technology was used in a similar way in a team-taught class at Maynard Computer Mini-School. The teachers of a mixed fifth/sixth-grade class focused much of their attention during the first part of the school year on teaching students how to work together in collaborative groups. Different groupings were used for book clubs, research assignments, and other classroom work. Group interactions were videotaped, and the videos were used in teacher-structured processes of reflection on what worked and what did not work well within the groups.

Although technology appears to support the socialization of school tasks, as described above, we should note that the classrooms benefiting most from these technology capabilities were those in which cooperative learning skills were a focus and were given explicit training. Classes and whole schools participated in programs in which students learned expectations for interacting with each other, the responsibilities of differentiated roles for cooperative work, strategies for coping with conflict, and the qualities of helpful comments and constructive feedback.

Heterogeneous Groups—One of the by-products of collaborative work on complex tasks is the definition (or evolution) of differentiated roles. The Video Club at Bay Vista Elementary, for example, organized itself into production teams for the recording of school events. Each team consisted of a producer/director, who would oversee the entire production; a camera person responsible for operating the camera and taking care of all video equipment; and a production assistant, who would take care of the unexpected needs that arise during production. The production team for student-mounted events (such as the student news broadcasts at a local cable station) included script writers, production editors, "computer mavens" and artists who created titles and graphics, and "the talent" (students who appeared in front of the camera). Students took turns filling these roles for various events.

At John Wesley Elementary, the fifth-grade students working on the Multicultural Heroes project conducted their videotaped interviews in teams of three. One student was the interviewer, another student operated the video camera, and the third student took notes and served as a critical observer (interjecting questions or comments as needed). After the interviews were completed, the team worked together to transcribe their data at the computer. One student entered text at the keyboard while the other two operated the video recorder, assisted with spelling, and repeated words and phrases as they were being entered.

When complex tasks, collaborative teams, and technology are brought together, a great variety of skills are needed. Command of the subject matter, strategies for obtaining information and solving problems, communication and cooperative skills, and technology skills are all needed. Students who may not excel in one area are likely to excel in another. Especially when students are explicitly taught how to work together in productive teams, the teams evolve to function effectively, with students making diverse contributions.

In many classrooms, teachers purposefully composed groups of mixed abilities, ethnicities, and genders. In classrooms of mixed grades, the ages of students within groups also varied. Such heterogeneous groupings allow for multiple perspectives and diverse skills, enhancing the quality of project work and creating new avenues for individual specialization and peer tutoring.

Performance-Based Assessment—Educational reformers call for new kinds of assessment embedded within learning activities and capturing the kinds of skilled intellectual performances that are the real goals we have for our students (Frederiksen and Collins, 1989). Technology supports this practice when used in the context of meaningful tasks and projects because it provides products (student writing, multimedia presentations, computer simulations, spreadsheets) that can be stored, duplicated, shared, and discussed.

Classrooms in our case study sample, like many classrooms nationwide, were actively developing student portfolios, and much of the work that went into these portfolios was generated using technology. We were disappointed, however, in that most of the schools and classrooms had not gotten very far in developing criteria for assessing the material in student portfolios in a way that would permit evaluating student performance relative to a set of specific content standards or aggregating information about performance across students. In this regard, the classrooms reflected national trends.

Summary

On the whole, the site visit observations and interviews supported the contention that technology supports the implementation of the kind of constructivist learning activities described in our theoretical model. Some aspects of the model may be directly stimulated by technology—notably an increased level of collaboration, heterogeneity of roles, and greater complexity and authenticity in assigned tasks. Other aspects, such as involvement with content that incorporates multiple academic disciplines, may not be caused by technology per se, but are often reinforced by technology use.

Frequency of Technology-Supported Project-Based Learning

It is important to point out that although our case studies provided some rich examples of technology-supported classroom projects exemplifying the characteristics in our model, such activities were not the norm even in most of our case study schools. If a visitor were to go to one of these schools, chances are there would be interesting technology-supported projects going on in some but not a majority of classrooms at any given time.

There are multiple reasons for this. First, project-based teaching places tremendous demands on teachers. Teachers need to think deeply about the things that are most important for their students to learn and to design or adapt projects that will support learning those concepts and skills. They must learn to structure their classroom in such a way that different students or groups of students are working on different aspects of their project at any one time. To do so requires also that they teach their students how to work cooperatively and that they develop skills in supporting student interactions. They must learn to diagnose the thinking of individual students, even when those students are working in groups. And they must develop skills in supporting their students' thinking while still leaving the student the autonomy to explore and test out new ideas. This kind of teaching calls not only for a high degree of pedagogical skill but also for broad content knowledge and for continually tackling new material (Knapp, Means, and Chelemer, 1991). Schofield (1995) documents the stress this kind of change in teaching style imposes on even the enthusiastic teacher convert:

> *It was a ninth-grade class, and most of the kids in the ninth grade have already worked in a class where a number of things are going on at a time, so it didn't bother them at all. It drove me crazy, but I could see it was benefiting them. I felt torn. I wanted to be with this* [person]. *I wanted to be with that group. It was just a question of convincing my soul that when there is noise and everybody is doing something different, learning is taking place.* —High school teacher quoted in Schofield (1995), p. 109

Adding technology to the mix exerts yet another set of demands. We have argued above that the combination of technology and a project-based approach to teaching is powerful because it exerts pressure to rethink and restructure all aspects of the classroom. The other side of this double-edged sword is that teachers are being asked to make major, labor-intensive changes, and some if not many will be reluctant to do so. In Schofield's (1995) study of an urban high school in which few classes made use of technology, a teacher candidly expressed his reluctance to make the investment required to change:

> *I'm the old-fashioned type. I don't want to learn anything new....after so many years, you build up a file on your subjects.... For me to go into teaching computers... I would have to start all over. I would have to actually sit down and work everything out, and it would require a lot more work on my part to run a class the way I want it run.* —High school teacher quoted in Schofield (1995), p. 125

Technology-supported constructivist approaches are particularly energy-intensive for teachers who themselves have not been taught in this way and who need to acquire both the pedagogical and the technological skills required. Even when they have mastered the needed skills, many teachers find it difficult to sustain constructivist teaching approaches over time. At East City High School, one of the most project-oriented of our sites and a center for teacher development, several ACOT teachers expressed the need for periodic "rest" from these highly demanding pedagogical approaches.

Another reason why project-based learning is not more uniformly practiced in the classes at schools we studied is that there are circumstances under which approaches we have characterized as more "conventional"—practice on specific skills, teacher-led discussion—are well suited to the particular student and content at issue. By promoting the constructivist, project-based model of teaching, we do not mean to suggest that all instruction for every student should employ this approach all of the time. We would say, however, that every student should have ongoing, frequent exposure to this kind of teaching and learning and that every teacher should be capable of using this approach with facility. While many teachers are making great strides in increasing their use of project-based constructivist pedagogy, others remain unconvinced or uninterested. Introducing technology as part of the innovation does not make the model easier to implement, but we have seen that it can provide a powerful catalyst for taking on the challenge.

9. EFFECTS ON STUDENTS

In the previous chapter, we examined the effects of instituting technology-supported project-based learning in the context of our theoretical model of constructivist teaching and learning. In this chapter and the next, we take a more inductive perspective, summarizing the themes that emerged from the cross-case analysis.

Teacher Reports of Effects on Students

During the course of our fieldwork, we observed 17 classes or computer labs at sufficient length to develop separate descriptions (see Volume 2: Case Studies). We interviewed teachers in these classrooms about the effects that technology had on their students. Table 8 presents a categorization of the teacher responses, along with an indication of the number of observed teachers who made each point.

Motivational Effects

The most common—in fact, nearly universal—teacher-reported effect on students was an increase in *motivation*. Teachers talked about motivation from a number of different perspectives. Some mentioned motivation with respect to working in a specific subject area, for example, a greater willingness to write or to work on computational skills. Others spoke in terms of more general motivational effects—overall orientation toward working on school tasks, satisfaction with the immediate feedback provided by the computer, or the sense of accomplishment and power gained in working with technology:

> *Kids like the immediate results. It's not a result that you can get anywhere else except on the computer.... For them it really is a big deal—much more so than I ever thought it was going to be.* —Elementary school teacher

> *Technology is the ultimate carrot for students. It's something they want to master. Learning to use it enhances their self-esteem and makes them excited about coming to school.* —Fifth-grade teacher

> *The computer has been an empowering tool to the students. They have a voice, and it's not in any way secondary to anybody else's voice. It's an equal voice. So that's incredibly positive. Motivation to use technology is very high.* —Elementary school teacher

In many of these classes, students choose to work on their technology-based projects during recess or lunch periods. A number of teachers describe opening their classrooms before school

Table 8

TEACHER-REPORTED EFFECTS OF TECHNOLOGY ON STUDENTS

Observed Effect	Number Reporting[a]
IMPROVEMENTS IN STUDENT PERFORMANCE	
Technical skills	15
Accomplishment of more complex tasks	14
Increased use of outside information resources	10
Enhanced creativity	9
Improved design skills; ability to present information better	7
Improved understanding of audience needs	7
Higher-quality products	7
Increased likelihood of editing own writing; better editing skills	4
Greater consideration of multiple perspectives	3
Improved oral communication skills	2
MOTIVATIONAL EFFECTS	
Increased motivation	16
Heightened self-esteem	11
Improved behavior, such as attendance, time on task	5
CHANGES IN STUDENT AND TEACHER ROLES	
More collaboration with peers; peer teaching	13
Better self-regulation of own learning	11
Students teaching teachers	5

[a] Out of 17 case study teachers.

and during lunch for students who desire access to the computers. One elementary school teacher cheerfully reported that he had had to train his students to say, “Hello, Mr. G.! How are you?” before asking “Can I use the computers?” when they arrive early in the morning. The computer lab at the Maynard Computer Mini-School is well populated with students engaging in self-selected activities both before and after school.

Teacher reports regarding increased student motivation and self-esteem were supported by our classroom observations. Throughout our site visits, students were eager to share their computer-supported activities and products with us. They were obviously proud of their technical skills and of the type of work that they are able to accomplish with technology. Their demonstrated ability to exceed many adults in mastery of technology is highly motivating for students:

> *I told my mom all the stuff on the computer that she didn't even know. That was fun because I feel like I'm the mom.* —Middle school student

Luckily for us old fogies, many older students seem to develop tolerance for our technology deficits:

> *It's always an enlightening experience when you have a teacher come up to you and say, "Could you help me with this?" or "Could you get this for me?" You've got to remember they didn't grow up with this* [technology]. *They grew up with the typewriter!* —High school student

Another reason why technology is so motivating for many students is their realization that technology skills will be required for so many jobs in the future. Unlike much of what students are asked to do in school, they can envision a direct link between the acquisition of technology skills and a satisfying adult life:

> *The world is getting more technological and scientific. You'll have to learn, you'll have to know* [how to use technology] *or you won't survive.* —Middle school student

> *I think if you practice doing all of the technology we have here, when you go out of school...when you want to get a job, they'll pick you over somebody that doesn't know* [how to use computers].... *It's an advantage.* —Middle school student

Teachers also frequently cite technology's motivational advantages in providing a venue in which a wider range of students can excel. Compared with conventional classrooms with their stress on verbal knowledge and multiple-choice test performance, technology provides a very different set of challenges and different ways in which students can demonstrate what they understand (e.g., by programming a simulation to demonstrate a concept rather than trying to explain it verbally). Teachers and students are sometimes surprised at the level of technology-based accomplishment displayed by students who have shown much less initiative or facility with more conventional academic tasks. For many students, the feeling of mastery, as well as the social recognition that often accompanies such accomplishments, can truly make a difference in one's sense of efficacy as a learner. Not surprisingly, most teachers report also that technology use *enhances student self-esteem*. Exhibit 11 provides descriptions of the effect that accomplishing things through the use of technology had on the self-esteem of two individual students.

Exhibit 11

Increases in Student Self-Esteem Arising from Technology-Supported Accomplishments

A teacher at the Progressive School cites the case of one of her students as an illustration of how technology makes it possible for students who do not normally excel at academic tasks to become class "stars."

An Elementary School Student

> *My favorite is this boy...who had major problems at home. He figured out a way to make music by getting the computer to play certain letters by certain powers and it changed the musical tone of the note, and he actually wrote a piece. He stayed in every recess.... When I asked him what he was working on, he wouldn't tell me. Then he asked if he could put his HyperCard stack on my computer because it was hooked up to speakers. I said "sure" and at recess...he put it on my computer and played his music and literally stopped the room. And for months he had kids begging him at recess, every recess, to teach them how to make music. And for that particular kid it was the world because he really was not successful academically and was having lots of problems.... This really changed him for that school year.*

A Middle School Student

The mother of a seventh-grader at the School of the Future described how the school's program and the technology supports it offers increased her son's achievement level, motivation, and self-esteem. At his previous school, the boy had been unhappy and suffered from low self-esteem. He was bored by mathematics and uninterested in learning multiplication tables. In language arts, his work was hampered by poor spelling and sloppy penmanship. At the School of the Future, he was able to use technologies such as the word processor and the spell checker to circumvent these latter problems and concentrate on the meaning of what he was writing. He was given the option also to skip ahead in mathematics and finally conquered the multiplication tables so that he could take algebra in the seventh grade. At the end of 2 years there, he was an eager, confident student who was performing well above grade level in a number of areas.

Both the increased competence students feel after mastering technology-based tasks and their awareness of the value placed on technology within our culture appear to lead to increases in students' (and often teachers') sense of self-worth.

> *When you work on the computer, you feel smarter. It's like—"I know how to do that!"* —Fifth-grade student

> *I see more confidence in the kids here.... I think it's not just computers, it's a multitude of things; but they can do things on the computers that most of their parents can't do, and that's very empowering and exciting for them. It's "I can sit down and make this machine pretty much do what I want to," and there's something about that that gives them an extra little boost of, "Wow, I'm a pretty special person."* —Elementary school teacher

Students clearly take pride in being able to use the same computer-based tools employed by professionals. As one teacher expressed it, "Students gain a sense of empowerment from learning to control the computer and to use it in ways they associate with the real world." Technology is valued within our culture. It is something that costs money and that bestows the power to add value. By giving students technology tools, we are implicitly giving weight to their school activities. Students are very sensitive to this message that they and their work are important.

Students commented during interviews that using computers made them feel special and important. More often than not, students also reported that they preferred working with the computer to other, more traditional tools (e.g., textbooks, pencils and paper). A school-administered survey conducted at the School of the Future indicated that 70% of the students thought that the computer "made learning more fun."

Improvements in Student Performance

Teachers for the classes and activities observed at the case study sites were nearly unanimous also in reporting that students were able to handle *more complex assignments and engage in higher-order thinking skills* because of the supports and capabilities provided by technology. Teachers report that students are more able and willing to edit their texts and engage in critical rereading when writing at the computer. Math tools, such as spreadsheets and LOGO programs, can assist students in gaining greater conceptual understanding through concrete interaction and feedback. Science simulations allow students to observe and manipulate multiple aspects of complex microworlds. Database software provides students with a tool for gathering and analyzing large amounts of information in different ways. Across all of these applications, the technology itself poses a problem-solving challenge as students learn to master the features of the tool to accomplish their desired goal. Further, the computer tasks are often done in collaboration with peers, which in turn adds a new layer of complexity through the feedback and the communication requirements that working with others entails. Exhibit 12 provides some classroom examples of technology's role in supporting students as they undertake activities calling for higher-order thinking. One of the teacher's from the CSILE class described in Exhibit 12 talked about ways in which the structure of the communal database her students used supported their learning of important concepts:

> *There's a lot of high-level knowledge embedded in it that they're not even aware that they are using. They have to produce summaries... All these things you used to teach out of a workbook and it didn't make any sense. Here it's a direct application. They need to be able to do this in order to access something. So it's automatic that they learn how to do it because they want to be able to access. Like with the Book Talk, they apply key words to their summaries, so that someone can scroll through and see, "Now here is a book on family problems..." So making that kind of link, being able to synthesize your thoughts...there's actually an application on CSILE for linking, so they can link one note to another, talk about what the connection is.* —Elementary school teacher using CSILE

Another student outcome that many teachers attributed to technology use was the production of *higher-quality products*. This outcome was cited in relation to many different types of technology-supported activities, such as video production, multimedia projects, animation, and research. Students in a fifth-grade classroom were in the process of editing and producing a videotape on multicultural heroes, which they planned to market to other classrooms. Students involved in a city-building project at the Progressive School put together a multimedia product incorporating carefully edited text and *QuickTime* video for presentation to visitors and at conferences. At the School of the Future, middle school students created complex, professional-looking animations with *HyperCard*. At one of the TeacherNet high schools, where students use the Internet to research report topics, both the students and the teachers said that the reports were of higher quality in terms of the breadth, recency, and comprehensiveness of the information incorporated.

Writing and desktop publishing were widely regarded as areas that had been positively affected by the use of computers. Teachers reported that students produced higher-quality texts when writing with the word processor and often were more willing and able to edit their texts in this context.

Exhibit 12

Examples of Technology-Provided Supports for Advanced Thinking Skills

A Middle School Math Class

The math teacher reports that technology supports enable students not only to produce higher-quality graphs but also to understand graphs at a deeper level and to be able to examine the relative strengths and weaknesses of different graphic representations. In an activity designed to introduce students to the use of spreadsheets to calculate, analyze, and present quantitative data, students first estimated the length of various parts of their own bodies (e.g., wrist circumference) and then made actual measurements. Both sets of data were entered onto a spreadsheet, from which students then began to experiment with different ways of representing the data. Because the physical production of the graphs was handled by the computer, students could focus on making the conceptual link between the spreadsheet data and the visual representation. They worked collaboratively to determine what information to display and how best to display it. After trying a variety of representations (e.g., pie, line, and bar graphs), they were able to discuss the advantages and disadvantages of each for different types of data sets (e.g., pie graphs can display only one variable).

Students are asked to further reflect on their problem-solving process through the activity of writing narratives at the word processor describing their approaches and their results. Through a series of activities such as this, the teacher reports that students have gained an understanding of graphs that has extended across subject areas. At the request of other teachers who have observed this increased skill on the part of students participating in the math class, the math teacher has agreed to conduct a workshop on computer-supported graphing for the entire faculty.

A Long-Term Elementary School Project

In the Archeological Dig Project at Nathaniel Elementary School, the use of CSILE helped students organize and extend their thinking through collaboration with their peers. Students and teachers generated challenging topics about the culture under study (e.g., "What did the ancient Egyptians do to write numbers?" "What were their laws and government?"). A student who initiated a topic would be prompted by CSILE to figure out specific things that needed to be learned to address the topic. By posting the inquiry on-line, the student would get help from other students in figuring out ideas (actions) and resources (where to go for more information). Students would make on-line notes of information on the topic as they collected it, stimulating other students to add more information and interpretations. As students became more adept with the process of collaborative knowledge building through CSILE, their dialogues took on an impressive level of sophistication. For example, the group developing a number system for a hypothetical culture posted an illustration of the system with the linked text entry:

> *This is the slaminan's number system. It is a basic 10 number system too. It has a pattern to it. The number of lines increase up to five then it goes upside down all the way to 10.* —Student group in CSILE class

The group developing rituals for the same culture studied the entry and wrote a response pointing out the need to extend the system:

> *We all like the number system, but we want to know how the number 0 looks like, and you can do more numbers not just ten like we have right now.* —"Ritual group," CSILE elementary school class.

Teachers and students alike commented that the capability of creating written products similar in appearance to published print is a source of real satisfaction and pride for students.

> *If you're doing something like eighth grade research, you want it to look nice. You don't want childish, sloppy writing.* —Middle school student

> *For some of them, it makes them feel like they're finished. It looks really good—better than if they had done it with handwriting. It looks professional. . . . In that respect...I know the feeling myself...it puts a new luster on things. I think that if they didn't have that, they would not feel so big or so professional—that they have gone through everything that a real writer does. To have it published at the computer and typed up like that is more than if they had just done it by hand. It's like the difference between third and fifth grade.* —Elementary school teacher

Other frequently cited benefits of technology-based activities included enhanced creativity, the development of design skills, and improved thoughtfulness about the needs and interests of a potential audience. Experiences in developing the kinds of rich, multimedia products that can be produced with technology, particularly when the design is done collaboratively so that students experience their peers' reactions to their presentations, appear to support these qualities.

Multiple media give students choices about how best to convey a given idea (e.g., through text, video, animation). In part because they have the capability to produce more professional-looking products and the tools to manipulate the way information is presented, students in many technology-using classes are reportedly spending more time on design and audience presentation issues.

> *They also do more stylistic things in terms of how the paper looks, and if there is something they want to emphasize, they'll change the font...they're looking at the words they're writing in a different way. They're not just thinking about writing a sentence; they're doing that, but they are also thinking about, "This is a really important word" or "This is something I want to stand out." And they're thinking in another completely different way about their audience.* —Elementary school teacher

Although most teachers were positive about the design consciousness that technology fosters, a potential downside was also noted by a few teachers. It is possible for students to get so caught up in issues such as type font or audio clips that they pay *less* attention to the substantive content of their product. We observed one computer lab in which several students with a research paper assignment spent the entire period coloring and editing the computer graphics for the covers of their as-yet-unwritten reports, pixel by pixel. A middle school student reported that when writing at the computer she often got caught up in worrying about the kind of type to use ("You think about what kind of writing you want it to be in, plain or . . ."). Teachers are developing strategies to make sure that students do not get distracted by some of the more enticing but less substantive features of technology, for example, by limiting the number of fonts and font sizes available to the students.

The *greater use of outside information sources* was an effect of technology use cited by teachers from 10 classrooms. This effect was most obvious in classrooms that had incorporated telecommunications activities, but other classes used technologies such as satellite broadcasts, telefacsimiles, and the telephone to help provide access to external sources of information. Schools with links to the Internet reported that the network brought "the outside world" into the classroom, enabling students to gather data directly from a wide variety of sources and to learn about life beyond the classroom walls through interpersonal communication with e-mail participants from around the world. Students at the Maynard Computer Mini-School studying Ireland for their schoolwide multicultural fair, for example, used the Internet to interview Trinity College students and to obtain information on historical artifacts from the College's database.

> *Sometimes children...are very isolated because they don't get to go many places. But through this communication over the computer they are able to relate that Ireland isn't just a place on a map but that there are people living there, and through e-mail they get a response. A lot of them have pen pals all over the world.* —Elementary school teacher

An example of how activities can be developed around use of the Internet was observed at one of the secondary schools participating in TeacherNet. Students in an Electronic Research class were first exposed to a variety of electronic search tools, such as DIALOG and Veronica searches (with Gopher) on the Internet. Students then used the tools to collect, analyze, and synthesize information pertaining to four thematic projects: student rights, habitats, pollution, and AIDS research. For the habitat theme, students were challenged to think about how they might colonize a planet of their choice. Working in groups of two or three, they used the Internet to search for information about various planets and to download GIF (graphics interchange format) files, such as images of Jupiter's moons. The data were used in developing their designs and writing their reports.

> *I think the availability of all the different resources, DIALOG in particular, to access all the different databases...it's really a help to teachers because they get to bring things in and share them with their classes.... Instead of information that's 2, 3, 4, or 5 years old, the computer can get the most current and up-to-date information. I have had endless numbers of teachers come to me and say, "I am such a better teacher now. I have access to current information. I got it at home last night."* —Secondary school principal

Students too find that the currency of information they can gather over the Internet gives them a greater sense of being part of the world of national and global events:

> *I have looked at articles* [on the Internet] *that aren't 20 minutes old.... For example, the day Kurt Cobain's body was found, I went home and I heard it on the radio. The first thing I did was I called* [the local network connection] *and looked at the UPI.... There were already four or five different articles...like his impact on society...actual new accounts, different experiences of the band members...a lot of up-to-date information.* —High school student

A number of classrooms using either wide area or local area networks extensively reported positive effects on students' inclination to consider *multiple perspectives*. When students conduct searches on the Internet, for example, they are exposed to the idea that there are many different sources of information and varying perspectives to be brought to bear on a particular subject. Engaging in electronic-mail communication with individuals from distant locations further exposes students to perspectives that differ from their own.

Teachers at the Maynard Computer Mini-School, where students make extensive use of Internet resources in conducting their research projects, suggest that the active engagement in finding and querying information resources, especially human information resources, leads students to develop a different stance toward information. Rather than something inert that is cut and dried and captured for all time in a textbook, information is something that exists all over the world, changes constantly, and can be viewed from multiple perspectives.

> *The kids were able to contact Trinity College in Ireland* [over the Internet] *and ask for information from college students.... It makes kids realize that information is happening right now and it's not just in a textbook. And textbooks can be wrong. And there's always a perspective on a textbook...let's get it from someone who is really living there instead of from a textbook...* —Fifth-grade teacher

Changes in Student and Teacher Roles

An impact of technology cited by a great majority of teachers is an increased inclination on the part of students to *work cooperatively* and to provide *peer tutoring*. The CSILE classrooms, described above, were designed explicitly to take advantage of network technology as a support for cooperative work. As multiple groups of students worked concurrently on their respective portions of their hypothetical culture, CSILE helped the groups keep in touch with each other's progress, an important activity because the various aspects of a culture need to be consistent.

> *Student groups created graphic and text notes to explain what their cultural universal was. Then other students could access that and comment back right away and say, "Wait a minute; you can't make a boat out of a tree because our*

> *culture doesn't cut down trees!"* —Elementary school teacher from CSILE classroom

While many of the classrooms we observed assigned technology-based projects to small groups of students, as in the CSILE Archeological Dig Project, there was also considerable tutoring going on around the use of technology itself. Collaboration is fostered for obvious reasons when students are assigned to work in pairs or small groups for work at a limited number of computers. But even when each student has a computer, teachers note an increased frequency of students' helping each other. Technology-based tasks involve many subtasks (e.g., creating a button for a *HyperCard* stack or making columns with word processing software), leading to situations where students need help and find their neighbor a convenient source of assistance. Students who have mastered specific computer skills generally derive pride and enjoyment from helping others.

In addition, the public display and greater legibility of student work create an invitation to comment. Students often look over each other's shoulders, commenting on each other's work, offering assistance, and discussing what they are doing.

> *I've also seen kids helping each other a lot at the computer. The ones that pick it up faster, they love teaching it to someone that doesn't know it yet.* —Fourth-grade teacher

> *The ones who have used it from the beginning have become peer coaches.* —Fifth-grade teacher

We observed only one school where many students preferred working individually on technology-based projects without interacting with each other, even sitting with nothing to do rather than pairing up at a computer if there were not enough to go around. At this school, a fear of disclosing one's password and making computer files vulnerable to destruction by other students appeared to work against the inclination to collaborate. But even within this school, we observed individual classes in animation and home design where the teachers encouraged collaboration, and students viewed and commented on each other's work ("Cool!") and offered assistance with each other's designs. In general, unless students are expressly directed to avoid discussion during computer work or are put into a physical environment that makes discussion difficult (for example, put in carrels and given headsets for computer-based work), technology appears to promote interaction rather than isolation.

Many of the teachers also report that the introduction of technology creates many more occasions on which *students are teaching teachers*. At one school we observed a trio of students working with their teacher after school, patiently guiding her step by step through her first lesson in word processing. Such activities support a shift in student and teacher roles toward the kind of "community of learners" that many educational theorists advocate (Brown et al., in press).

Going along with this change in roles, teachers see a positive effect of technology on students' inclination to *regulate their own learning*. Several teachers commented that the computer allows students to engage in independent learning activities and to work at their own pace.

Teachers are often pleasantly surprised by their students' ability to manage long-term, complex technology-based assignments. In addition, technology can provide supports for self-regulation. CSILE, for example, is designed to support students' learning by providing a structure that facilitates student reflection on their own and others' thinking. One teacher noted that students become more adept at identifying the gaps in their own thinking and understanding through their participation in CSILE, as they make their knowledge explicit and receive specific feedback from others.

More generally, the network configuration and interface set up for a number of sites provided supports for students to take responsibility for their own learning.

> *Students know that if they are absent, they have immediate access to look up materials on the network without the need to stop the teacher from instruction to the rest of the class. Students can mail in assignments on the network. Items are dated and time stamped when they are turned in. Teachers can collect materials at their convenience rather than taking away valuable learning time while with the students.* —Secondary school technology coordinator

The network also supports greater student responsibility for managing their own behavior by allowing students to work on assignments from any location. A student in a social studies class who has finished her assignment can log on to the server and work on her assignment for another class. Technology can function as a tool for monitoring growth and self-progress through feedback and the automatic maintenance of a running record of a student's work. A variety of technologies offer opportunities for students to critically examine their own and each other's work, for example, through viewing videotapes of exhibitions or performances or through electronic transmission of one another's texts for review and editing.

Some teachers also report *improved behavior* in areas such as attendance and time on task. A number of the technology-using classrooms we studied reported having fewer behavioral problems than other classes and more students who were willing and able to stick with a task for long periods of time. In part, this effect seems related to motivation and the degree of absorption that typifies technology-based tasks:

> *Technology contributes to the sense that they always have something that is high-powered to do, which is motivating.* —Elementary school teacher

One of the teachers we interviewed perceived an additional advantage of computer-based activities in calming students who are having emotional difficulties or trouble concentrating:

> *The computer room is a place where a lot of the kids, if they are having trouble with their behavior or emotions, they will ask to go.... I think it soothes them, and there is no pressure.... It focuses them off whatever was bothering them and gets them back on track.... It can take a child who is very unfocused and having distress in the classroom, and you can see them...they are not breathing heavy anymore...even just logging on.* —Fifth-grade teacher in inner-city school

For many sites, the school's engagement in technology-based activities had attracted outside attention and numerous visits. Some of the sites have hosted hundreds and even thousands of visitors in a single year. Past visitors have included prominent individuals, such as state legislators, members of the National School Board Association, a state governor, the Chairman of the Federal Communications Commission, and the President of the United States. Teachers from two classrooms noted that as a result of experiences in showing visitors how technology is used within the school, students had gained confidence and improved *oral communication skills*. Given the facility displayed by a number of the students we interviewed, this contention is easily believed.

Finally, nearly every teacher cited the concrete *technical skills* that students had acquired and the advantages that such skills would give them in later education or employment settings. The level of expertise acquired by students varied both within and across sites, in relation to the level of access that was provided as well as in relation to individual student interest. Students with the most sophisticated skills were often those who engaged in frequent self-selected technology-supported activities, in addition to their regular coursework. What was striking overall, however, was the large numbers of students who were quite comfortable with the equipment and had achieved a basic level of competency in using technology as a tool.

> *They are not going to have the phobias we have* [about technology]. *They have discovered a lot.* —Elementary school teacher

> *When I first came to* [this school] *I really didn't know anything at all about the Macs other than there's a little switch in the back—you turn it one way, it turns on.... That's basically all I knew. I first started out with just the word processor...and then I started getting into games and I took a HyperCard class and that really got me started.* —Middle school student

Evaluations

A number of the case study sites have conducted self-studies or evaluations of their programs, either in response to state or other funding accountability requirements or as a tool for improving their programs. Several of these were quite detailed (e.g., South Creek, School of the Future, John Wesley) and included data from student, teacher, and parent surveys as well as the kinds of statistics normally collected by districts. Other programs maintained surprisingly little data; this tended to be true particularly for the schools-within-schools, which were not required by districts or states to collect data on the subset of students they served. Impediments to conducting systematic evaluations, of course, include lack of funding and expertise. Two of the schools with the most complete evaluations (the School of the Future and John Wesley) both received foundation funds to support this activity.

Even when the data maintained by a school were extensive, however, they did not provide a simple answer to the question, “Does technology work?” In every case, the site was implementing many more changes than simply the introduction of technology, and students, teachers, and other school variables were not completely comparable with those of other schools within the district or state. As Joan Herman (1994) points out, we should not be surprised by this situation. By their very nature, education reforms are multifaceted. We need to ask not the simplistic question of whether technology “works” but rather more detailed questions about specific effects of specific uses and kinds of technology. Nevertheless, to provide a sense of how the case study sites measure up in terms of traditional education indicators, we have provided a summary of available data in Table 9.

These data were collected by the schools or districts, and the available comparison group (other schools in the district, students not in the mini-school, performance prior to the innovation) varies by site. In reviewing the data, the reader should remember that we specifically chose to look primarily at sites serving substantial numbers of students who live in economic poverty. Even so, the sites vary considerably in the demographics of their student populations. A rough indicator—the proportion of students receiving free or reduced-price lunches—is provided. Overall, the site indicators are positive . Out of the 8 single-school sites, 7 reported lower-than-average rates of teacher turnover; 6 reported high student attendance rates; and 5 had higher standardized test scores than some comparison group. Of the 6 schools providing reports regarding rates of student discipline problems, 5 could point to lower rates of disciplinary incidents than experienced by some comparison group. Although these variables were not measured in the same way across all the schools and in some cases there may be questions about the suitability of the comparison group, the overall picture is an encouraging one. In the final column of the table, we present some of the key variables other than technology per se that might contribute to the measured outcomes

Table 9

INDICATORS FOR CASE STUDY SITES

Site	% Free/ Reduced Lunch	Test Scores	Attendance	Discipline Problems	Teacher Turnover	Other Outcomes	Nontechnology Factors
Bay Vista	25%	Students showed >1 year's growth on CTBS science subtests in '87-'88; significant gains on tests of science process skills in '89	Above average for district	Below district average for district	Low		Hands-on science curriculum; highly involved parents; close-knit teaching staff
East City High School ACOT	40%	Much higher percentage pass state proficiency tests than in rest of school, but test is given in fall of 9th grade	Higher than rest of school	Not available	Low		Smaller class size; interdisciplinary, student-centered approach. Students must apply for program; 37th percentile on CTBS required

John Wesley	100%	Scores fluctuate across grades and years between 30th and 50th percentiles on state standardized tests	Improving over past 3 years	Declining over past 3 years	Low		High percentage of students with limited English; poor match between program and standardized tests; integrated thematic instruction; emphasis on emotional as well as cognitive growth
Maynard Computer Mini-School	77%	Mini-school students gained more than school's other students on one reading and three math subtests for '90-'91	Not available	Better than rest of school	Lower than rest of school	Mini-school students do well on city, state, and national competitions (e.g., poetry, chess)	Students selected from those whose parents apply; mini-school has smaller classes and more cohesive program than rest of school

Table 9

INDICATORS FOR CASE STUDY SITES (Concluded)

Site	% Free/ Reduced Lunch	Test Scores	Attendance	Discipline Problems	Teacher Turnover	Other Outcomes	Nontechnology Factors
Nathaniel Elementary	85%	Second-graders scored in 7th–14th percentiles on CTBS tests in ’92; sixth-graders at 19th–30th percentiles	High for district	Low for district	Low		Very large classes; high student mobility; high proportion of limited English
Progressive School	23%	Higher scores than other schools in the area despite more ethnic and SES diversity	High	Not available	Low		Extremely close-knit, dedicated staff; cohesive, student-centered curriculum; high parent involvement
School of the Future	80%	Standardized test scores in mathematics declined over first two years; by ‘92 scores returned to level of original incoming class (slightly above national average)	High	Varied across time	High		Standardized tests not matched to curriculum; following negative publicity about test scores, school has gained reputation as a “school of last resort”

South Creek Middle	65%	Higher scores on state tests than schools serving comparable populations; 45%, 59%, and 72% of seventh-graders mastered state objectives in reading, math, and writing, respectively, compared with 42%, 42%, and 62% for similar schools and 53%, 52%, and 69% for state as a whole in '93	High	Low compared with year of opening	Low	0.5% dropout rate compared with 3.9% for state; high teacher satisfaction shown on survey; at end of school's first semester, its students ranked 2nd in district on math objectives despite the fact that it was 2nd lowest in district in SES	Teach 90 minutes each of math and language arts daily; teacher team approach; high level of limited English among students

10. EFFECTS ON TEACHERS

In discussing evidence of technology's role in supporting aspects of our education reform model in Chapter 8, we described the most significant effects of technology on teachers' classroom behaviors as they directly impact students' learning experiences—increased likelihood of assigning complex, long-term projects; organizing the class into collaborative learning groups; and acting as coach or facilitator for the projects rather than as the transmitter of information. In this chapter, we discuss the impact of technology on other aspects of the teacher's job—preparation of classroom presentations and materials, classroom management and assessment, and collaboration and professional contacts within and without the school.

Effects on Classroom Management and Presentations

Although our conceptual model and, hence, our observations stress giving technology tools to students, teachers also can take advantage of the capabilities provided by new technologies for presenting and organizing information in ways that were not feasible in the past. Technologies such as laser disc, satellite- and cable-transmitted video, and projection panels to display computer screen images were in common use within many of the classrooms at the case study sites. At Bay Vista Elementary, for example, a third-grade teacher used a projection device to allow her students to view living bacteria in a petri dish. At the School of the Future, a system that connects student terminals to a teacher's workstation allowed a teacher to display almost instantly the consensus of the class during brainstorming sessions. At East City High School, students in a geometry class took turns demonstrating different ways to construct a triangle with a geometry software package, with the computer screen image shown to the entire class by means of an LCD projection panel.

Less common but significant was the teacher use of software to prepare computer-based activities specifically for their own classrooms. At the Progressive School, where the teachers had the advantages of paid consultantships to engage in this kind of work and ample technical support, we observed a number of exciting teacher-developed applications. A primary teacher built a *HyperCard*-based application that links student computer drawings with their compositions and with a standard English version of the composition that the teacher develops in conference with the student ("That is how the word sounds, but this is how adults spell it."). When the results are printed, students, their parents, and the teacher have a record of the student's original art and writing along with a standard English version that is much easier to decipher.

A teacher in a class with a year-long curriculum theme of marine ecology used *HyperCard* to create a "Planet Ocean" simulation in which students go deep-sea exploring in a bathyscaph to collect video clips (from a laser disc) of underwater life. The simulation contains four increasingly difficult "missions," which students must complete within specified time limits to maintain adequate oxygen, given different ocean depths. An on-line "research book" provides text information that students can use in trying to identify and understand the marine creatures shown in the laser disc images. Students use the video clips they collect and their text notes to prepare research presentations for the class.

Another way in which technology enhances teachers' ability to present information is by providing capabilities for easy tailoring of materials for individual students or groups. One of the classrooms studied at the Progressive School made this kind of tailoring a general practice so that the teacher-developed exercises students worked on were better linked to student interests and abilities and to the activities of their specific projects.

> *Like our first step in the commission book* [a portion of the city-building project] *this time—we wanted them to find facts. So with the computer it was really easy to make the basic outline to finding facts and adapt it for each book and each commissioner so that it was really exactly on target for what they were doing and what the book was about. Instead of...giving each child the same thing that wasn't perfect, we got eight different commission things that had the same basic idea but that were very related to what they were doing.* —Elementary school teacher

Teachers who have access to computers for personal use and who have been given the support to develop technical skills are much more likely to produce their own instructional materials with the aid of technology than are those who are not given these types of resources. The extensive support in both these areas provided by Apple to the teachers at the Progressive School led to the creation of highly innovative and sophisticated instructional programs and materials, such as those described above. At John Wesley, the entire faculty was reported to be using computers for the preparation of classroom materials after each teacher had received a Duo computer for his or her professional use.

Technology can be used also to support teacher management functions, such as instructional planning, grading, report preparation, and attendance monitoring. Many of these functions are built into the software that comes with integrated learning systems (ILS), for example. The classrooms we studied were not ILS labs, however, and use of technology for management purposes was spotty. The most consistent use of such tools was at South Creek, where all teachers used *Class Master* for attendance and grading purposes. A number of teachers talked about the software as a tool that can reduce the time and effort that goes into routine tasks, allowing for greater focus on more substantive issues. A mathematics teacher felt that it had advantages also for reflecting on the efficacy of her instruction:

> *It* [technology] *frees a lot of our time to spend getting things ready for lessons, looking for things to do in the classroom. Otherwise, we would be constantly grading papers, averaging and stuff like that, and the computer does it for us. We just grade the papers and put it in and it will weight it, average it, and everything. It frees us up.... I can take the information that the computer will generate and I can do different things with it. I can organize it in different ways to show me where there's a weakness, where the majority of my kids fall when there's an activity.... It allows me to focus in on..."Did I not teach it well enough for the kids or was it something that was beyond what...they could do?"* — Middle school mathematics teacher

Teachers at several other sites used software for attendance and grading, as well as for such purposes as cataloging instructional software or other resources. At the Bay Vista school, for example, databases are used to catalog instructional materials, schedule staff development activities, chronicle special events, and record the results of teacher and student surveys.

A number of teachers used general-purpose applications (such as *HyperCard*) in their instructional planning. Teachers in one classroom made oversized banners displaying the titles for their major curriculum units and put them up on the wall as a way of giving their students a sense of the plan for the year and where they were with respect to it.

The School of the Future undertook an ambitious attempt to use software in planning and monitoring individualized instructional programs for their students. School staff worked with programmers from a nearby software firm to develop the Pupil Growth Planning (PGP) system. The system supported teachers in creating course syllabi, asking them to identify key process and product outcomes within the course, and providing a template for monitoring and reporting student progress on these outcomes. The system was designed also for use by students, parents, and faculty advisors in defining the student's individual academic and personal goals, identifying courses and resources to help fulfill those goals, and monitoring progress against the resulting action plan. When students and their advisors entered individual goals, the system would use a keyword search to identify appropriate courses, mentorships, and other resources. Although never fully implemented, the system also provided an electronic mail feature that could be used for communication among students, parents, and teachers.

Many teachers used technology in one way or another as part of assessment activities. In some cases, such as the CSILE classrooms, teachers took advantage of the computer's capability to store a record of student activity to review the development of student products as a way of getting a better handle on the areas in which the students experienced difficulty. In schools with local area networks, teachers often had ready access to student file folders, which enabled them to monitor their students' work and individual progress with greater care and ease. Teachers also remarked that students' use of the computer made their work much easier to read, making it easier to assess the substance of the work without struggling over legibility or reacting to a poor physical appearance. Portfolios of technology-produced work (essays, multimedia presentations, videos) were fairly common. Many of the teachers were involved also in preparing narrative reports of student progress, and word processing software was typically used for this purpose.

Teacher Collaboration within the School

Reflecting on her school's 7 years of experience with the extensive use of technology, one of the site principals remarked:

> *If we've gotten nothing else out of all of this* [technology], *it...gives teachers an invitation to share their ideas about instruction. This is something they're not expected to know already; it's not competitive.* —Elementary school principal

Staff at several sites remarked that the introduction of technology had put them into the position of being learners again. Their common struggle to master something new led to increased contact, both in terms of receiving from fellow teachers the same kind of support for technology use that was described above for students and in terms of sparking discussions about what they were teaching and how technology fit into their instructional goals.

> *My team* [other teachers working with the same group of middle school students] *was the most supportive group. If one of us didn't understand and somebody else understood it, during our team planning, we'd sit down and we'd teach each other.... We all felt a little bit overwhelmed, because a new school is overwhelming, but throw the technology on top of it and we really felt overloaded, but we had a wonderful team. We've always had a wonderful team, so we worked well together.* —Middle school teacher

At John Wesley and Bay Vista, joint activity in framing education reform and technology implementation grant proposals increased the amount of teacher interaction around issues of curriculum and instruction. At East City High School, South Creek, and the Progressive School, the provision of supported time for teachers to present and talk about their technology-based activities led not only to sharing of information and strategies dealing with technology, but also to an increased sense of camaraderie and better articulation of the curriculum.

> *We've had faculty meetings where we have presentations, so the teachers that have done projects using technology, they've presented it to the whole faculty; and we saw what was going on, so we knew and could say, "Hey! Maybe we could make it easier for you if we introduce this skill at this level and then in seventh grade take that skill and take it to another level, and by the time they get to you, it's going to be a snap for the kids."... If we didn't have the opportunity to see* [what others are doing with technology], *there would be much more overlapping and not taking it a step further. We're trying to spiral it as much as possible.* —Middle school mathematics teacher

Nathaniel Elementary provided support for teachers participating in specific technology projects (CSILE and Project GALAXY) to work together and share insights.

The provision of teacher planning time is a key underlying factor in determining both the extent to which technology gets used and the level of teacher collaboration that occurs within a particular site. In schools where supported time was provided for planning and sharing what the teachers were doing with technology, such discussions appeared to be both an important unifying factor and an instigation for the spread of technology use to additional classrooms. In other technology-using schools, where time for joint planning or observation of each other's technology-based activities was not provided, the technology introduction per se did not produce a sustained climate supporting teacher collaboration, and widespread technology use was less likely.

Another way in which technology can support teacher collaboration and cooperation is through the use of electronic mail for teacher-to-teacher communication. At South Creek, teachers reported using the electronic mail system to communicate with other teachers within their team about students they share:

> *The e-mail is wonderful because the whole concept of a middle school is to communicate and to try to have a core block of students going from teacher to teacher to teacher* [within a team].... *So if I have a question about a child in my room...I can e-mail and find out who has them next, and say, "Look, I've noticed something; I'm not sure if it's just me or they've had a bad day, but let me know what you think." And we can get responses within minutes; they just e-mail us right back and say, "I noticed the same thing yesterday," or "I'll keep my eyes open."* —Middle school teacher

South Creek teachers also had set up e-mail groups around different curriculum areas (e.g., social studies, science), and teachers used the system to circulate enclosures with ideas for projects to do together.

In addition to South Creek, teachers at East City High School made extensive use of electronic mail to communicate with each other. Other single-school sites made less use of electronic mail for communication within the school. In most cases, they lacked a system at the time of our site visit. (John Wesley, for example, brought in electronic mail after our site visit.) In some cases, however, schools with electronic mail reported that teachers continued to depend on the exchange of hard-copy notes, rather than taking advantage of the technology that was available to them. In general, our observations indicate that the existence of the technology infrastructure per se is not enough to overcome a general attitude of teacher independence and lack of widespread interest in group planning or coordination. These attitudes must be addressed before electronic communication technology can provide its full benefit for teacher communication and collaboration.

Teacher Interactions with Outside Collaborators and Resources

Technology has the potential also to support a much greater degree of communication and collaboration between teachers and others outside the school walls.

> *I don't know of any other profession in the world that isolates themselves more from what others do than teachers. We walk into our classroom. We close the door, and there is no connection with the rest of the world. Networking is going to change that.* —TeacherNet teacher

TeacherNet was designed in large part to fulfill the need for interactions and sharing of resources across schools. Most of the materials in the TeacherNet curriculum library, in fact, were developed by groups of teachers from multiple schools collaborating over the network. In this sense, the project offers demonstrable proof of the capabilities of telecommunications to support broader collaborations among teachers. At the same time, the majority of teachers in TeacherNet schools are not using the network to interact with peers at other schools. The same access issues that limit the network's use by students hinder its effectiveness in supporting teacher interactions. Most teachers in TeacherNet schools do not have their own e-mail addresses, and many lack training in how to use the network.

Teachers at some of the other sites reported communicating with teachers or others outside of their school around aspects of their technology-supported projects. At the Progressive School, one of the teachers we interviewed had done a number of joint projects with teachers at another school. Both students and teachers have shared ideas and project products over the network and through the exchange of videotapes. Teachers at Progressive and at East City High School ACOT communicate with other classrooms supported by Apple. At Nathaniel, there were plans to connect the teachers using CSILE with other CSILE classroom teachers in 1994–95.[6] Project

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6. CSILE was linked with other classrooms in the first year of the project. Teachers rarely took advantage of this line of communication, however, no doubt at least in part because the school's only modem was located in the computer lab rather

GALAXY was supposed to include communication among teachers at different sites, but problems with getting the technology (in this case, satellite-connected facsimile machines) to work properly led teachers to give up such efforts. At South Creek, the industrial arts teacher uses the network to communicate with other industrial arts teachers and the coordinator for his district, and the computer literacy teacher communicates with her peers throughout the state, but other teachers we interviewed did not report active use of the network for such purposes. At Maynard, the computer coordinator makes extensive use of the network to interact with people interested in educational uses of telecommunications on a national level. The mini-school's other teachers have made little use of their wide area network connection for such purposes, however.

In addition to telecommunications support for interacting with people outside the school's walls, technology-based innovations may provide the motivation for non-network-based collaborations (just as they can motivate such collaborations within the school, as discussed above). One aspect of technology-related professional development activities, to be described below, is the fact that they bring teachers into contact with outside resources, including not only other teachers but researchers, politicians, software developers, and administrators.

Teacher Professionalization

One of the major effects of the technology-supported education reform efforts for teachers was an increase in their involvement in professional activities. Project-related teacher professionalization enhancements can be roughly classified into two categories: (1) activities and changes in circumstances that were a part of the reform effort or technology implementation per se and (2) increased opportunities for professional activities and state- or national-level exposure that arose as a side effect of involvement in technology innovations.

- Activities that were part of the projects themselves included:
- Grant writing (for teachers at John Wesley, Progressive School, Maynard Computer Mini-School, East City High School, and Bay Vista).
- Training in technology use (for all nine sites).
- Greater access to technology for own use (for John Wesley, Progressive School, School of the Future, South Creek, East City High School, Maynard Computer Mini-School).
- Collaborations with outside researchers (for Nathaniel, Progressive, and Maynard Schools).

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than in the teachers' classrooms. The current plans for linking CSILE schools coincide with Nathaniel's plans to enable broader access to the Internet.

- Increased role in school decision-making (for John Wesley).
- Collaborations with software developers (for Progressive and School of the Future).

Such activities are important not just because of what teachers learn from them but also because of their effects on teachers' self-esteem and morale.

> *The only reason I stay here is that they give you all this training, the tech training and the science training. They're not afraid to spend money on it, and that's really a feather in our caps as teachers.* —Fourth-grade teacher

Some of the most rewarding professional experiences described to us took place at sites with strong ongoing collaborations with external research or development groups. At the Progressive School, for example, Apple Computer paid teachers as consultants to work on developing instructional applications during their 3-week breaks. Teachers were involved also in field testing experimental software. At Nathaniel, teachers trying out CSILE had extensive interaction with the software developers and their site support team. While teachers received valuable insights into how the CSILE software might support what they were trying to do in their classes, the developers received feedback from the teachers on how the system was working. For example, teachers pointed out that the original interface was too difficult for their students to navigate; students were much more successful with the system after a new interface was implemented. In this way, the teachers gained experience as professional collaborators in a research and development activity. Similarly, at Maynard Computer Mini-School, the computer coordinator has had a long-standing relationship with external research teams, sharing in the development of research proposals and the ongoing design of research activities as well as in the resulting funding. Across the case study sites, many teachers reported that their involvement as field experts in the piloting of new technology tools and programs contributed to their sense of professionalism.

Exemplary use of technology in ways that support education reform are not widespread. For this reason, the experiences and perceptions of staff from the case study sites have been of great interest to a broader educational community and, indeed, to the general public. Professional opportunities stemming from involvement in technology-supported activities have included participation in state technology committees; election to offices in regional and national educational technology associations; receipt of funding for disseminating instructional uses of technology; participation in additional state pilot programs; consulting contracts with software developers and others, including the Edison Project; published articles in a wide range of education-related journals; being interviewed for broader mass media publications such as *Newsweek*, *Fortune*, *Business Week*, the *Los Angeles Times*, and the *New York Times*; and being the subject of national-level television documentaries (PBS and BBC). Table 10 provides a partial list of the conferences and publications where case study site staff gave presentations or published articles.

Table 10

PRESENTATIONS AND PUBLICATIONS BY STAFF AT CASE STUDY SITES

Conferences Participated In	Journals/Newsletters Published In
Computer Using Educators (CUE)	*CUE Newsletter*
National Educational Computing Conference (NECC)	*The Electronic School*
Institute for the Transfer of Technology to Education (ITTE)	*Computing Teacher*
Jostens Technology Conference	*Educational Leadership*
Technology and Information in Educational Services (TIES)	*Electronic Learning*
Association of Teacher Educators (ATE)	*California Science Teacher's Quarterly*
Association of California School Administrators	*Thrust for Educational Leadership*
National Education Association (NEA)	*California Technology Project Quarterly*
Early Childhood Education (ECE)	*Science Education Academy of the Bay Area (SEABA) Journal*
Elementary School Science Association (ESSA)	*California Classroom Science*
California State Teachers Association (CSTA)	
Chapter 2 Conference on Technology in Education	

Conclusion

The education reform movement challenges teachers to transform their practice by adopting:

- High expectations regarding what all their students can accomplish
- New curricula emphasizing higher-order skills
- Constructivist, student-centered teaching methods.

Across the study sites, we found classrooms where technology was supporting movement toward these goals by providing students with new capabilities and teachers with both stimulation for their thinking about learning activities and evidence of what highly motivated students can accomplish with technology tools. At the same time, only a minority of classrooms even approached the model of technology use in the reformer's vision for classrooms of the 21st century. These were classrooms where teachers were already open to project-based, student-centered approaches and where the school environment provided supports in terms of opportunities for teacher collaboration, adequate levels of technology access, technical assistance and supported time for learning about technology, and recognition and encouragement for technology-supported projects. Although there is much to be done to develop a system that supports the broader application of technology use and constructivist teaching and learning approaches, the reports of teachers in classrooms where these innovations have been integrated suggest that the combination is a powerful one. Indeed, we found that active involvement in technology-supported innovations had become a source of inspiration and professional renewal for many teachers.

11. IMPLICATIONS FOR POLICY, PRACTICE, AND RESEARCH

How can education reform and technology's positive role in that reform proceed? Critics such as Cohen (1988) and Cuban (1986) provide a sobering perspective on the prospects for real change. It won't just happen; certainly the installation of networks or the purchase of computers, videodisc players, or satellite links, even in much larger quantities than we see today, won't automatically bring about the transformation in student learning activities that reformers envision. Our case studies and earlier research on technology-supported implementations provide insights into the issues that policy-makers and practitioners must confront if technology is to make a difference in our schools. In this concluding chapter, we consider the implications of our study findings for policy, practice, and research.

Implications for Policy

Although the United States still has the most decentralized education system in the industrialized world, many states are taking a more and more active role, taking on curriculum and programmatic decisions that were formerly district and school prerogatives. In California, for example, curriculum frameworks set specific learning goals in seven content areas and suggest instructional approaches. Florida is requiring all schools to develop plans to attain specific state-mandated outcomes. In the technology area, Texas is setting standards for student and teacher workstations and is phasing in standards for weekly access time. By the end of 1995, nearly every state will have a new state technology plan, which is a requirement for participation in Goals 2000.

The justification for state planning and activity is particularly strong if technology is considered an integral part of reform because states can garner both technical resources and leverage in equipment and software purchases that would be hard for a school to duplicate. States have an important role also in striving for equity across communities with very different levels of resources.

Nevertheless, our case studies echo earlier findings in suggesting that top-down technology-based reform efforts are less effective than those that have a strong local base (e.g., Berman and McLaughlin, 1978). At John Wesley, whose district had given every school a satellite dish, the equipment sat idle, in part because teachers did not know how to download and store broadcasts so that they could use them at appropriate times during their school day, but more fundamentally because teachers had not been interested in integrating this technology in the first place. At the

School of the Future, the large ILS lab that was purchased for the school by its district was spurned by the teachers in regular classes for several years; students were sent to the lab as scheduled, but the teachers did not try to draw any linkages between the ILS curriculum and what they were teaching in class, and in fact did not even know what the students were getting in their ILS lessons. These examples suggest that approaches in which a higher level of the education system decides what equipment schools will get or how they are to use it, and teachers do not participate in the process of thinking through instructional goals and selecting technologies to match them, are likely to lead to wasted resources.

At the same time, we would not advocate an entirely bottom-up approach. With no support, guidance, or encouragement from the system, a few exceptionally dedicated teachers will put in the time and energy to conceive and implement exciting technology-supported projects, at least for a while. Their students will benefit from their work and gain a new confidence in their ability to learn using technology. Most students will never receive this kind of instruction, however, if there is no systemic support for it. Innovations have a fragile existence, particularly when they are not consistent with district or state curricula and accountability measures. Without institutional support, innovations often die off when their champion leaves or becomes discouraged. One of our case study sites was clearly vulnerable to the potential loss of its technology leader; the district correctly perceived the technology as a one-person show because the technology coordinator's expertise had not been transferred to a significant number of teachers.[7]

In addition to the greater staying power of innovations supported by the broader educational system, there are significant economic and political arguments for broader-based reform efforts. Initiatives involving telecommunications technologies require larger-scale involvement by their very nature. Economies of purchasing and planning technology acquisitions argue for the involvement of state- or regional-level agencies (Council of Chief State School Officers, 1991). States also have an important role in guaranteeing equality of access. Student homes vary dramatically in the amount of technology available, and without state action, differences among schools serving advantaged and disadvantaged students are likely to reinforce such inequalities.

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7. In contrast, another site that had provided incentives and supports for all the teachers to learn to use technology (Progressive) did lose a strong leader (as well as most of its corporate sponsorship) toward the end of our case study period, but had enough momentum and commitment across the teaching staff to continue its technology-based work.

Mixed-Initiative Approaches to Innovation

The model that appeared most effective across the case studies was one we have called a "mixed initiative" (Means et al., 1993), in which the higher level of the system provides a structure within which lower levels of the system are invited to design innovations that may receive funding and become part of a dissemination network (David, 1991). This philosophy is the general approach embodied at the federal level in the Goals 2000 initiative. When applied at the state level, the state takes the lead in setting an agenda for reform but recognizes the importance of local initiative and of letting classrooms and teachers "reinvent themselves." Under this model, the state's role is to create the structure for reform, but not the detailed content. The basic state strategies for encouraging local reform initiatives are:

- Recognition of outstanding programs
- Funding opportunities for locally developed programs
- Technical assistance
- Waivers from regulations.

In the technology area, more specific actions states may take include:

- Model schools programs
- Support for in-service training in technology and instructional uses of technology
- Funding for local development of technology-based materials
- Development of a telecommunications infrastructure.

Under this mixed-initiative model, the state provides leadership and support but leaves the essential design and implementation issues to local control. This kind of state strategy had a significant impact on two of our case study sites. John Wesley received school restructuring funds from its state education agency, and Bay Vista became a model technology school for science. In each case, the education reform themes stressed by the state influenced the school's thinking about goals and desired activities, but the specifics of the innovation were locally determined by teacher teams, who consequently felt a strong degree of ownership. Although not directed at technology per se, the state charter school program in which Progressive participated is another example of state provision of supports for change without specification of the instructional program.

Encouragement of Partnerships

The combination of a growing activism on the part of business and civic groups and the shrinking education resources of states and districts has led to an increased recognition of the importance of forging partnerships outside the education system to promote the kinds of new programs reformers advocate. Many of our case study schools were heavily involved in such partnerships even before the rising tide of such arrangements evident in the last several years. Indeed, in assessing the degree of influence of players outside the school house, we concluded that partners outside the education system—corporations, foundations, and research groups—played a more significant role than state or local education agencies for our case study sites. The prominence of these external partners has led us to suggest, that in most cases, the education system by itself lacks the financial and technical resources for such technology-based innovations.

The importance of these external players suggests the value of federal and state policies that encourage partnerships; indeed, we have seen this trend in recent years with programs such as the Challenge Learning Grants and the New American Schools Development Corporation. Nevertheless, impediments remain in terms of the suspicion of external players (particularly business) in many quarters of the education community and the lack of awareness or interest on the part of many business partners in providing the essential human and intellectual supports for technology-supported innovations and the long-term support needed to see an ambitious change program to fruition. Just providing equipment or funding is not enough. To be effective, a partnership needs to include a shared understanding of education goals, the provision of resources for teacher training and professional development, and a commitment on both sides to working collaboratively. Our case studies included some very effective long-term partnerships with corporate or foundation partners, notably at Progressive, John Wesley, and East City High School. (See the case studies in Volume 2.)

An issue that was not fully addressed at our sites was that of sustaining the activity beyond the time frame of a partnership. Although corporations and foundations should be encouraged to engage in longer-term relationships, they cannot be expected to support any one school or group of schools indefinitely. The innovation needs to be taken over by the school and the education system, and generally there was no concrete planning for how this transition could occur. We did observe one example of a seemingly successful institutionalization of an innovation formerly supported by a corporation. After 7 years of intensive support from Apple, the Progressive School was transitioning to self-sufficiency during the 1994-95 school year. In this case, the teachers took on new duties (uncompensated), parents raised significant funds, and the school's charter provided a degree of flexibility in allocating funds that few schools enjoy. In addition, Apple provided maintenance training and interim continuation of technical assistance and other support at a decreased level during the transition year. Building a transition plan into partnerships and making plans for skill transfer and district funding at the conclusion of the special project are important considerations that are too often ignored.

Implications for Practice

In observing activities at case study sites and trying to understand the extent to which education reform and technology activities had really made a difference in what happens to students within the school, we came away with a two-part basic criterion for judging an effort as successful. In broad terms, the first feature of a successful program is the integration of technology use within a broader instructional vision. We sought schools that had achieved this integration for our case study sample; nevertheless, as one would expect, there were differences in the extent to which the school's staff and students shared a common view of the school's goals and technology's role within them. The second, and related, aspect of a successful program is the permeation of technology-supported activities reflecting this educational philosophy across classrooms. Even at some of the schools in our case study sample, there were many teachers who did nothing with technology or who used it only for word processing (typically after drafts were written out by hand). This degree of variation gave us the opportunity to examine the features associated with more and less successful sites in terms of the coherence of their instructional program and the breadth of implementation of compatible instructional uses of technology.

From this schoolwide perspective, the five features associated with more successful implementations were:

- ***Time devoted to developing a schoolwide vision.*** A consensus around instructional goals, and a shared philosophy concerning the kinds of technology-supported activities that would support those goals. Such consensus takes time to achieve, and although it requires instructional leadership, it also requires the active involvement of teachers. Site-based management and grant opportunities appeared to serve as catalysts for such discussions.
- ***Adequate technology access for all students.*** To the extent that there are only a few computers in regular classrooms or computers are clustered in a few labs in one part of the school, most teachers have little opportunity to integrate technology into their instruction and indeed feel little responsibility for doing so.

- ***Time for teachers to learn to use technology and to incorporate it into their own curricular goals.*** Particularly after the first initial hurdles, learning to use a new piece of hardware or software in a mechanical sense is a fairly short-term activity and can be accomplished through the typical in-service session. Thinking about how technology can support one's own instructional goals, however, and learning how to orchestrate a class in which students are doing challenging projects, portions of which are technology based, take much longer. These kinds of learning need to occur over time, preferably with opportunities to observe models, to practice, and to receive feedback on one's actions.

  One of the things we noticed after observing many technology-using classrooms at the case study schools was that the majority of the most interesting projects were designed by pairs of teachers or a teacher in cooperation with an outside researcher or trainer. (We will discuss the implications of this phenomenon further below.) One implication is that the kind of technology-supported education reforms being advocated needs to be supported by new policies and practices regarding teachers' time. South Creek and East City High School built in amounts of planning time for their teachers that are unusual across American K-12 institutions. Progressive had financial supports for large amounts of time outside the regular school session. Schools without such supports had a harder time getting a majority of teachers involved.

- ***Easily accessible technical support.*** Most schools have a few teachers who are comfortable with technology and able to do much of their own troubleshooting. But most teachers have limited experience in this area, and even if they are comfortable using a technology they have not completely mastered in front of their students, these teachers will not be willing to plan around technology use if there is a good chance they will encounter technical problems that they cannot get fixed for days or weeks. Our case study teachers, like those in earlier studies of technology implementations (e.g., Stearns et al., 1991), indicate the importance of having on-site assistance.

- ***Rewards and recognition for exemplary technology-supported activities.*** Like the rest of us, teachers are influenced by the reward structure around them when it comes to deciding where to place their energies. Not surprisingly, school leadership that values technology and education reform activities was associated with more widespread and sustained emphasis in these areas.

Within schools, we interviewed a great many teachers and students and observed many classrooms. From these, we selected two classrooms at each site on which to focus our data collection. Across all of the classrooms, including those visited only briefly, we drew some inferences about the features associated with successful implementations of the kind of technology-supported, project-based learning activities we were seeking.

- ***Good curricular content.*** Although in some cases the availability of new technology inspired a project (e.g., the production of multimedia materials about local leaders), in all cases the most fully developed projects had strong curriculum content and many components that were not technology based. The city-building project at the Progressive School and the archeological dig at Nathaniel are good examples of well-executed technology-supported projects that extended over long periods, interwove curriculum content from multiple disciplines, and incorporated a wide range of activities (including such things as making papier mâché objects, building scale models, and actually burying and excavating artifacts).

- ***A structure within which teachers can innovate.*** Many of the early technology enthusiasts dreamed of a "teacher-proof" system embodying sound principles of teaching and learning and engaging students directly without the interference of a teacher whose knowledge base might be incomplete or whose pedagogy might be faulty. Studies of classroom implementations of technology have demonstrated that this goal was not only unrealistic but wrong-headed. Teachers can subvert practically any kind of instructional material to their own goals and ways of teaching (Cuban, 1986). Thus, in newer conceptions, the teacher is an essential part of the instructional application of technology (Means and Olson, 1994). At the same time, it is unrealistic to go to the other extreme and expect a majority of teachers to develop their own instructional materials or software. In Chapter 2, we argued that tool and communication uses of technology have important advantages in their flexibility to fit with any teacher's curriculum goals. Nevertheless, many teachers will find it difficult to conceive of interesting projects that simultaneously fit with their curriculum goals and make use of technology. There is also the temptation to assign projects that use an exciting new technology but have little curricular value. We observed classes using animation software, for example, where the goal from the student standpoint appeared to be purely to get the biggest special effect (usually an explosion). Such content-free uses contrast with the *HyperCard* animation project at East City High School, where students had to compute the amount of evolution over time and represent this time scale in the animation stacks (see Volume 2 for a description).

  In the classrooms within our case study schools, many of the most successful technology-supported instructional activities seem to take a middle-of-the-road approach, in which there is a curriculum package with a set of basic instructional goals and suggested activities and strategies but the teacher has (or takes) the opportunity to modify the content and fit it to his or her class and local curriculum concerns. Both the city-building and the archeological dig projects were originally conceived by people outside of our case study schools. Having heard about these project ideas, our case study teachers modified and extended them and added the use of technology tools as a way to enhance the projects. Hence, the teachers were not starting from scratch, but they had had the opportunity to be creative and to try out and refine extensions of the original curriculum unit.

- ***Opportunity for teachers to collaborate with peers.*** Just as the difficulty of what we are asking teachers to do in moving to project-centered instruction implies an advantage for building on an existing curriculum structure, it also suggests that the support teachers can get from collaboration with their peers will be important. Across the classrooms we visited, many of the most ambitious and successful projects, like the city-building and archeological dig examples, were planned and executed by teacher teams rather than a teacher working alone. All of the well-known advantages of teamwork, such as multiple sources of inspiration, expertise, and energy, apply to the difficult job of bringing off a student-centered classroom. Further, when teachers work together, they seem to plan more far-reaching and ambitious activities than when they work in isolation.

- ***Teachers and students already comfortable with project-based learning.*** Bringing technology into a classroom and implementing student-centered projects is much easier if the teacher and students are already accustomed to collaborative learning. Having these skills in place means that the teacher and students are not trying to learn about a new technology at the same time that they are struggling with new roles and new structures for organizing classroom activities. Moreover, if students are used to working in small groups and with rotations, the problem of scheduling a limited number of pieces of hardware is easily solved by simply making it one of the classroom's rotations. Students who are used to the concepts of roles within a team, standards for offering constructive feedback, and dealing with each other politely will find it much easier to use these needed skills within the context of technology-based activities.
- ***Use of technology across subject matters and classrooms.*** There is a certain amount of "overhead" that goes with learning to use any new technology. Students need to acquire keyboarding skills and learn how to get into programs and files and to store their work in appropriate ways. Passwords and Internet search skills require a certain amount of knowledge that has nothing to do with most curricula and is unlikely to carry directly over into adult settings for any but perhaps senior high school students because of rapid changes in technology. Given this reality, the more classes and grades over which this "technology overhead" can be spread, the better. Teachers in schools that use technology throughout the school find it easier to use technology because they do not have to teach all of the technology skills themselves. Moreover, when technology is used across a broad range of classes, many more students find enjoyable uses and feel confident about their ability to learn new technology applications.

Setting a Research Agenda

Our experiences at the nine case study sites and our attempts to draw inferences for policy and practice from case study data and the existing research literature lead to some reflections on areas in which we would like to see more (or different) research.

Model Technology-Supported Network Activities

In trying to describe technology use, one is always chasing after a moving target. Although we made an effort to select some of our sites because of their involvement with wide area networks (WANs), the timing of our case studies (most conducted during school year 1993-94, some during

1992-93) was such that the majority of schools had fairly limited access to telecommunications and participated only sporadically in a few special activities such as National Geographic Kids Network. Our case studies did provide examples of the use of Internet resources in classes at Maynard Computer Mini-School and the TeacherNet schools (see Volume 2), but other case study schools offered few opportunities to observe WAN-based activities. Nearly every one of the schools with limited WAN access during the time frame of the case studies has received (or expects to receive during 1995-96) much better network access and intends to do more in this area.

With the exceptions of some well-documented activities conducted by the AT&T Learning Circles and the collaborative science projects of Kids Network, Kids as Global Scientists, and the like, the research literature offers few examples of telecommunications projects that are rich from an instructional viewpoint. Moreover, the research literature examples were planned and structured by outside corporate or research institutions. Given the pace at which school districts and states are investing—or considering investing—in network resources for schools, there is a need for rich descriptions of exemplary teacher-designed, WAN-supported activities at a range of grade levels and in multiple content areas.

Models for Third-Party Involvement

Many of our case study sites were heavily dependent on outside sources of funding, inspiration, and technical assistance. One inference that can be drawn is that the education system itself only rarely provides the level of support needed for schoolwide constructivist implementations of technology, at least in schools serving large proportions of students from low-income homes. Another, and more positive, inference is that we need to develop models for collaborative efforts to educate our children and youth. Schools and districts need more savvy in how to elicit and sustain parent, community agency, and business support. Agencies and corporations need a better understanding of schools' needs. Both sides need models for building sources of support for sustaining innovations beyond the first few years of funding.

Contextualized and Broad-Scale Studies of Effects on Student Learning

Finally, we return to the questions that policy-makers and the public ask about technology use in schools, "Does it work? Does it raise student achievement?" One of the purposes of this report is to illustrate the reasons why there can be no straightforward, black-or-white answer to these questions. Not only are there many different technologies, but there are many ways of using any one technology. Moreover, we have argued that the essential value of the kinds of efforts we have described lies in their education reform aspects and their provision of meaningful learning activities, not the network cables or computer screens per se. It does seem clear, both from our own case studies and from previous research, that the introduction of new technology can be a very effective motivator within classrooms and that, at the school level, technology introduction can help instigate a rethinking of school purposes and structures. Moreover, we have learned a great deal about the circumstances under which technology is more likely to really take hold and become integrated within the classroom practice of large numbers of teachers.

"But does it affect student achievement?" Both because the innovations we looked at were complex, with many facets other than technology, and because of the nature of the case study approach, we are not in a position to estimate the magnitude of technology's impact on student achievement. Most of the case study sites had some positive student learning results they could point to, either higher test scores relative to schools serving comparable populations or improvement over time on a measure they felt was appropriate to their program. But the standardized test score differences were generally not large, nor could we say with any certainty that they should be attributed to technology rather than to higher motivation, better teachers, enhanced camaraderie, or more complex tasks. As we have argued earlier (Means et al., 1993), there is a need for more contextualized research in which we try out technology-supported learning activities within classrooms and not only measure their effects on student learning but also study the way in which the learning activities are implemented and the many factors that affect that implementation. A few such studies have been conducted or are now under way (see Chapter 2), and they are providing evidence that particular technology-supported activities (such as the *Jasper* adventures and GALAXY science episodes) can have positive effects on student performance, including classes of low-income students. Nevertheless, such results are unlikely to satisfy national or local decision-makers who want to know whether the investment in networking and computers will pay off or to compare the likely value of a technology investment with those of other school improvement options (e.g., reducing class size or rewarding effective teachers).

The research literature offers a dated but large body of empirical data from studies of drill-and-practice computer-assisted instruction (CAI) and military training videodiscs but little on the kinds of technology-supported, constructivist, student-based activities reformers advocate. More recent studies are not only few in number, as mentioned above, but also characterized by a wide variation in the kinds of technologies and constructivist learning activities studied. Thus, it will take considerable time to build up a large enough corpus to permit the kind of meta-analysis conducted for CAI studies. To even begin to provide an empirical answer to questions about technology's efficacy would require a large-scale national study of a large enough sample of technology-using and control classrooms to permit the statistical removal of other probable sources of variation in learning outcomes (Herman, 1994).

Conclusion

The case studies we conducted for this project suggest that when the introduction of technology is dealt with as one aspect of a broader program of school reform, it can provide an impetus for a careful reexamination of learning goals and the design and implementation of challenging learning activities. When technology-supported projects are implemented, there is a concurrent pressure to restructure the school day and year. Both because technology-supported projects tend to be more complex and because it takes time to log on to a computer, call up the appropriate software, and execute a significant piece of work, teachers soon find that they need larger blocks of time for technology-based activities. Technology encourages the development of more complex products and also an iterative process of design, execution, and refinement. This multi-stage approach has the desired effect of facilitating the acquisition of higher skill levels and metacognitive awareness or reflection, but it should be recognized that it will also create pressure to spend larger amounts of time on each learning unit. Moreover, technology-based projects almost always require teachers to break their class up into subgroups working on different activities at any one time (if for no other reason than that there is generally a limited supply of one or more of the technology resources) and at the same time encourage more collaboration among students and a less didactic role for the teacher. All of these pressures associated with the use of technology reinforce practices advocated by constructivist education reform policies. It is for these reasons, and because of public recognition of students' need for technology skills in the world of work, we expect that technology to become an essential part of schools and a force for change.

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